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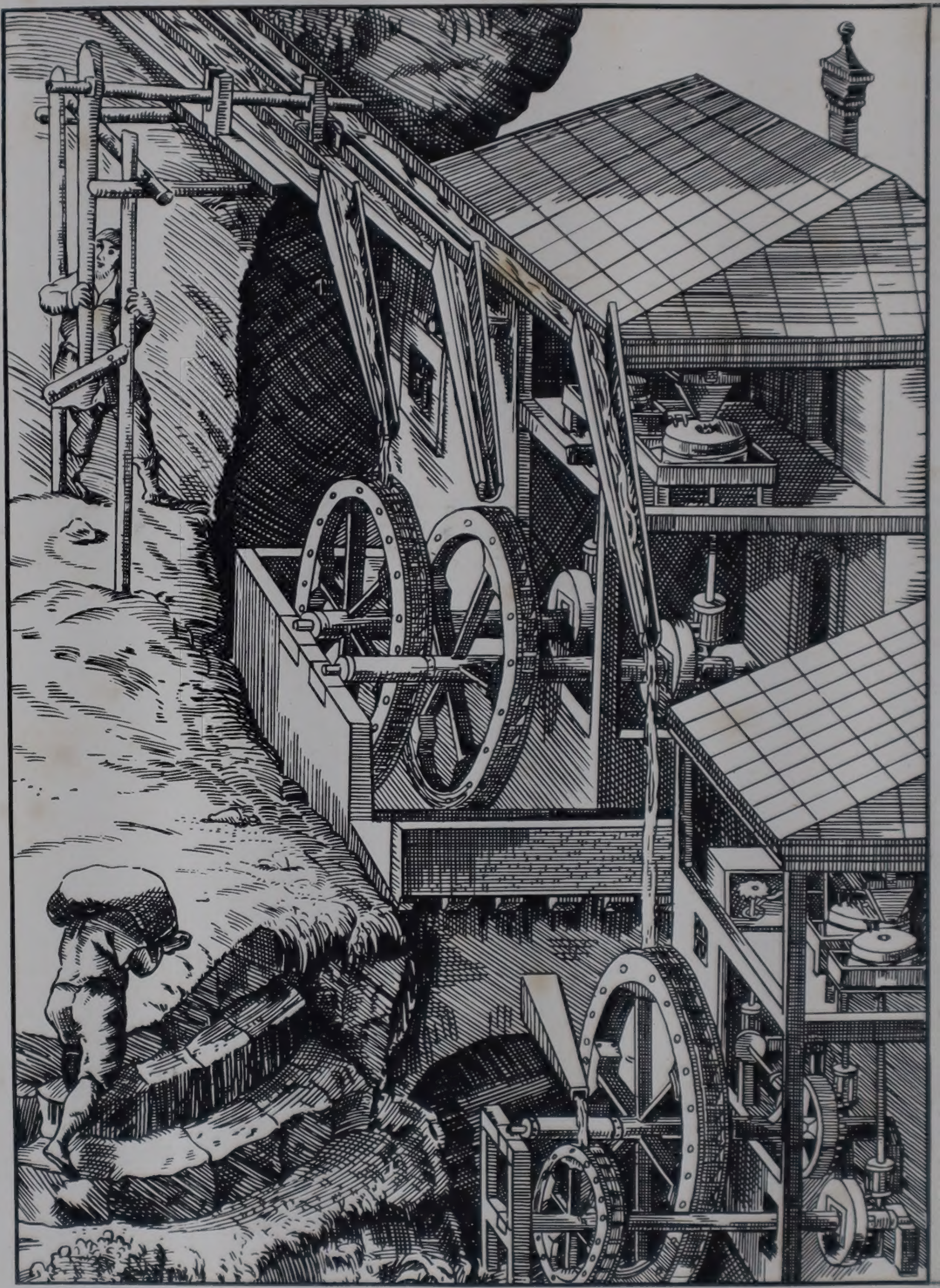
Flour for man's



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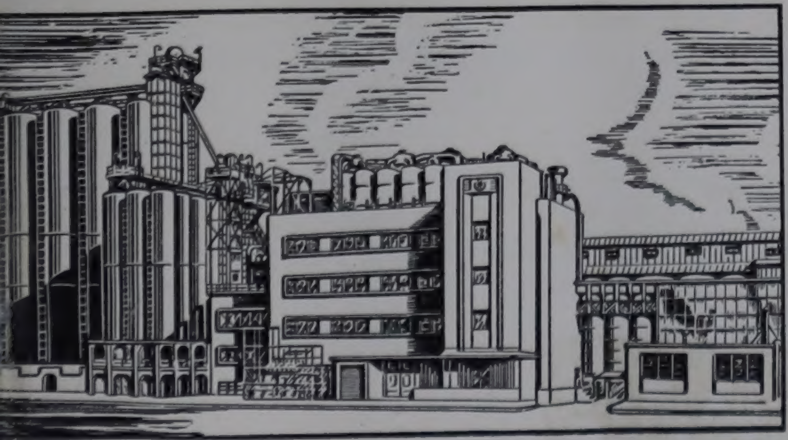
A HISTORY OF MILLING

FLOUR FOR MAN'S BREAD

by JOHN STORCK *and* WALTER DORWIN TEAGUE



illustrated by HAROLD RYDELL

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Frontispiece. Fanciful watermill group from Vittorio Zonca, *Novo Teatro di Machine et Edificii* (1607).

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Flour for man's..

Foreword

This volume brings to every reader many of the advantages of what was originally projected as a Museum of Milling History. The idea was seriously considered by General Mills in 1945. A tentative site adjacent to the headquarters offices in Minneapolis had been selected. It was planned to create life-sized moving dioramas to tell the story of the "ancient and honorable" craft of milling from earliest times to the present day.

Walter Dorwin Teague, the noted industrial designer of New York, drew plans for the museum and arranged for the necessary fundamental research. He engaged Dr. John Storck, scholar and author of a distinguished history of civilization, to delve into the past for knowledge in a field where he had few predecessors. The results of their collaboration, along with the excellent illustrations prepared under Mr. Teague's direction, are presented in this book.

Mounting costs and the materials scarcity following World War II forced abandonment of the museum project in 1947. The present volume, therefore, represents what *might* have been incorporated into a museum. Of itself, this book is believed to be the first complete exposition of the growth and development of flour milling, and its relation to man's progress.

Essentially, the history of milling records the effort of man to survive. His spark of life burns on the fuel of food. From the cereals springs his energy. They are the coals for his bodily warmth and well-being. Their discovery changed his mode of life. He was a wanderer on the face of the earth when a crack on its surface bound him to it. From the crack sprang the grasses, and from these came the cereal seeds. Man stopped in his wanderings to cultivate them. Of the cereals, wheat and maize emerged as best adapted to man's needs.

Man's molars were his first grinding tools. When these became inadequate, necessity forced him to invent other means. He rubbed the grain between two stones, to better purpose. He took his tools where he found them. He dropped them when they had served his ends. But as his understanding grew, he perceived that stones of certain forms were more efficient. These he shaped, and in the shaping gave them a value which he treasured. These forms were the mortar and the saddlestone. The Scriptures record their early value, for the Law of Moses provided, "No man shall take the nether or the upper millstone to pledge: for he taketh a man's life to pledge."

These devices gave him meal in quantity, but the grain seeds were small and the husks rough and numerous. To separate the husks from the meal, he invented the screen to sift them, and thus he obtained the first separation.

The rubbing together of the stones produced grit in the meal, which was most unpleasant and tooth-wearing. Man's ingenuity then suggested that the grit might be reduced if the stones used for grinding were slightly separated. Thus came the quern and the millstone, with surfaces which "reduced" the grain rather than ground it.

These were the first, and only, basic advances in the art of milling. The techniques and the tools were further improved, but flour milling today is still reduction and sifting, supplemented by air-classification.

The miller's tale recorded in this volume is necessary to an understanding of our modern industrial civilization. The ways in which man has made flour for his bread have forged the patterns of technological progress: the refinement of tools, the increasing use of power, the development of large-scale production and distribution. That progress has had far-reaching influence on man's social development. And the story is not ended. Research is pointing the way to as yet unknown possibilities.

In the words of the authors, "American millers may have their share in the most urgent business now before mankind – the business of raising the standard of living of the vast backward populations of the world, so that they too may become fertile fields for the spread of freedom and enlightenment."

JAMES F. BELL

Minneapolis, Minnesota
July 1, 1952

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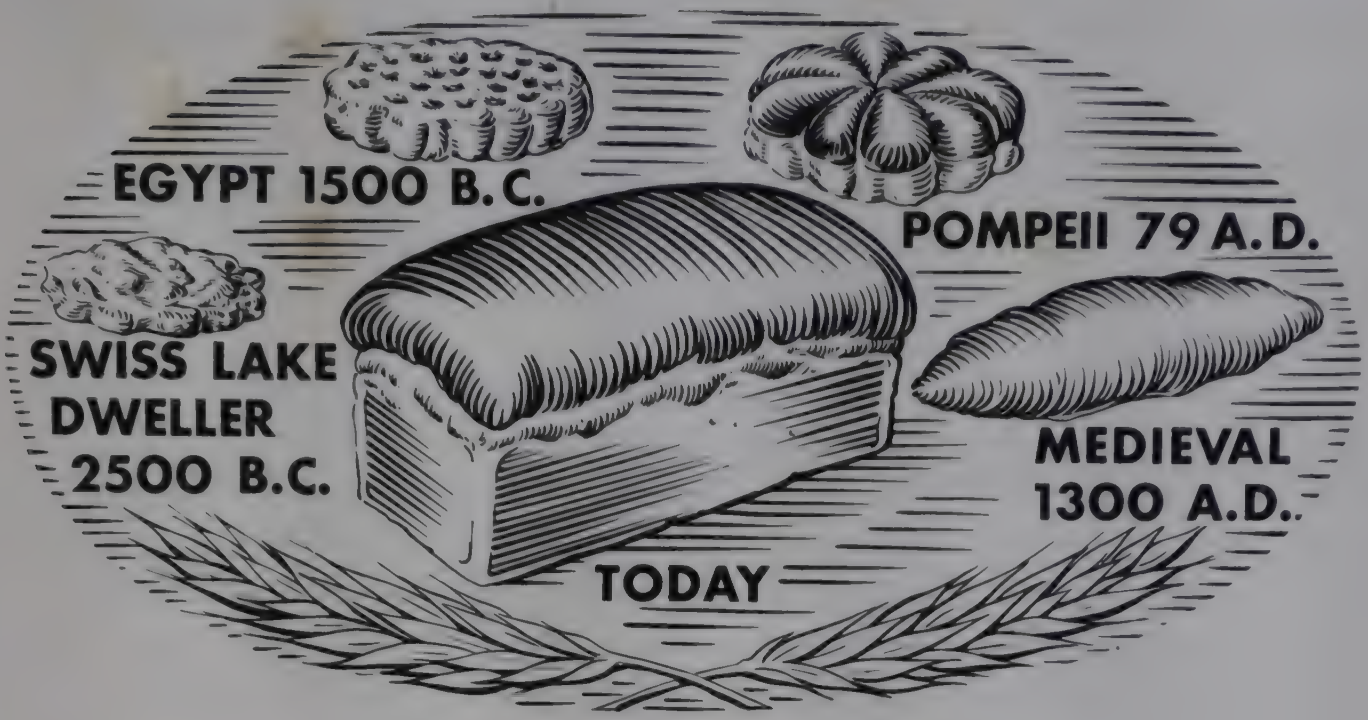
FLOUR FOR MAN'S BREAD



EGYPT 1500 B.C.
POMPEII 79 A.D.
SWISS LAKE DWELLER 2500 B.C.
MEDIEVAL 1300 A.D.
TODAY

Chapter head oval. Four and a half thousand years in the history of bread development.

CHAPTER I

The Line We Shall Follow

> Bread, milk and butter are of venerable antiquity. They taste of the morning of the world.
>
> —Leigh Hunt

A HEAP of white flour in a mixing bowl, ineffably fine, soft, pure. Flour, from which we make our daily bread, for ages principal source of the energy by which Western man has lived. Bread, symbol of life itself; in abundance the guarantee of well-being, in times of want the dream and the cry of the famine-ridden.

From the small, hard grains of a wild grass that some remote ancestor gathered and ground between his teeth—and probably swallowed with a wry face—to this flour of the bread we eat today is a long way, in time and evolution. And it is the way we intend to trace in our story.

That early experimenter with the seeds of wild grasses lived in an almost inconceivably remote past. His conclusion must have been that good and bad were somehow intermingled in the scratchy, pasty, bittersweet mess in his mouth. Today we are aware that all the edible grains consist of a nutritive nucleus, composed largely of carbohydrates and protein, enclosed in a hard, indigestible, cellulose shell (Figure 1). Birds can digest whole grains in their crops, men haven't that equipment. The outer shell must be broken up so that a man's digestive juices can attack the nucleus. But there are portions of the shell that are bitter to the taste, and its fragments are an uncomfortable kind of shard to pass through a man's sensitive alimentary canal. Yet for generations, probably millennia, men on occasion supplemented their meat diet by grinding grain between their teeth and swallowing the result whole – hook, line, and sinker, which metaphor is more apt here than is usually the case.

It was to be expected that someone in time would think of breaking up the grains between two stones in advance of chewing. Perhaps the idea first came to an elder who had formed a habit of eating the stuff but whose molars were not what they used to be. The use of stones for many purposes was already familiar. Man's first tool and weapon had been a sharp-edged piece of stone grasped in the fist – the *coup de poing* of earliest Paleolithic times. Stones had been used for cracking nuts, as country boys do to this day; and for cracking large bones to get at the marrow; and for cracking the skulls of people you didn't like. Why not for cracking the little hard grains?

This pregrinding was practiced only casually for many thousands of years, so long as men were primarily hunters and meat eaters. But there came a time when it acquired urgency, became a constant practice, a studied art. In the period when glacial conditions were moderating for the last time up to now, there were some who followed the arctic animals, their age-old prey, northward as the ice retreated. But there were other more independent souls who remained behind in the land they knew, perhaps because of that attachment to place that many animals display, perhaps because they found the warmer summers and milder winters to their liking. But in any case, they had the courage to meet the challenge of a changing world: instead of seeking regions where their old ways would still suffice, they were ready to learn new ways to survive.

With the mammoths and reindeer all gone, they came to depend more and more on small animals. They experimented with fish and shellfish – among them was that "brave man who first eat an oyster." Fruit and berries mysteriously offered themselves as the summers grew longer. And the grains: in regions where they grew, it was discovered that no plant food was more nourishing, more satisfying, and in time they began to bulk large in men's diet. It was then that men – and women – put their minds to the grinding of grain seeds, learned more skilled techniques, made stone tools better adapted to the purpose.

It was found that this pregrinding operation had another advantage, besides relieving the jaw muscles and the teeth and providing more food with less effort. When a handful of grains had been broken up between stones, it was possible to pick out and brush away many pieces of the

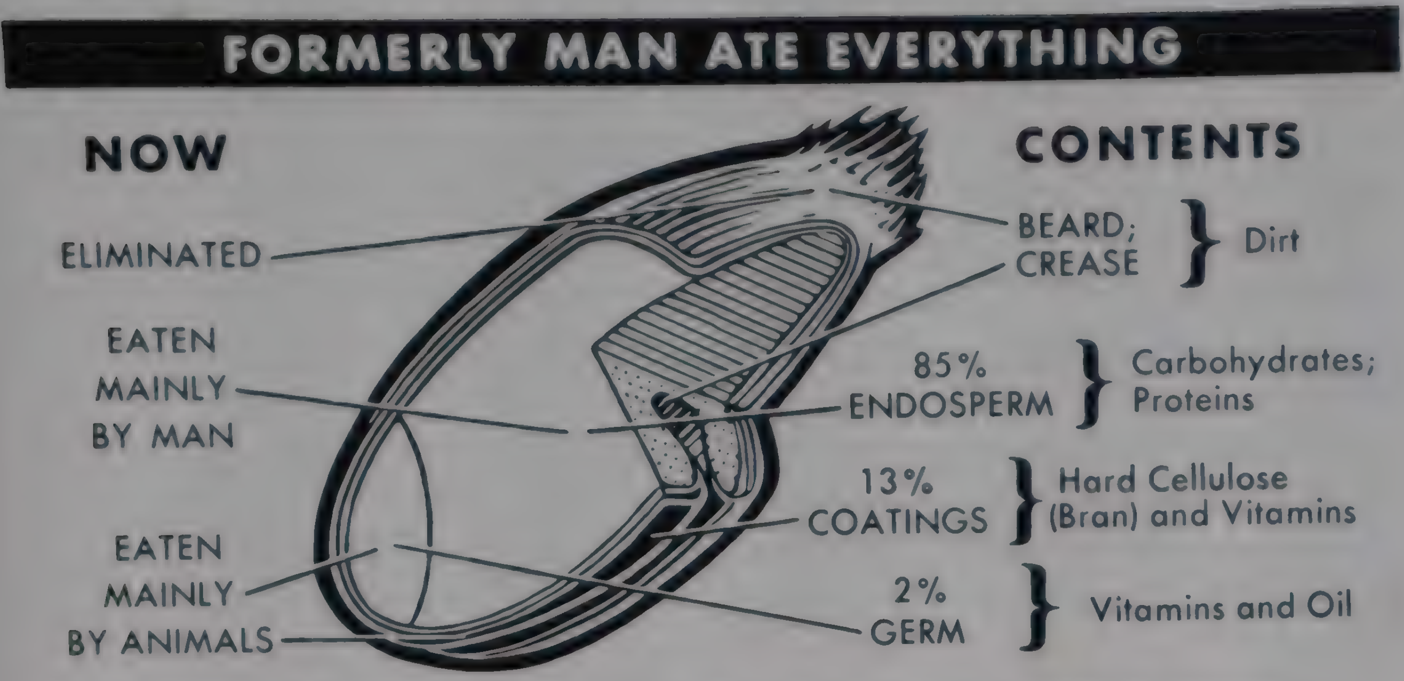


Figure 1. Schematic representation of the wheat berry, showing its principal parts and their disposition in early days and now.

harsh outer shell. The result was more palatable, a fascinating discovery. The business of getting rid of the unwanted particles acquired an importance almost equal to the grinding itself, and skills to accomplish it were developed. The ground meal could be picked over or sifted between the fingers, and the coarser fragments retained to be ground again or thrown away. Or the ground material could be tossed a little distance into the air, to winnow the unwanted lighter coatings away from the nutritious center of the berry. And after long ages, the first actual sieves would be contrived, out of stretched and pierced hides, or of loosely woven grass baskets.

Here in these two operations the story of milling, man's oldest continuously practiced industry, begins: the breaking up of cereal grain seeds, the removal from the resulting meal of the unwanted portions. These have been the basic processes of milling from its true beginning throughout its whole history, and they still are its basic processes today. The story we have to tell is the story of how we men have learned to do these tasks better and better, devising improved tools and new skills as time passed; enlisting forces of nature to help us; enlarging our mechanical arts and our mental capacities as we struggled with the twin problems of increasing the quantity and improving the quality of our product; adopting new ways of life, forming new social organizations as a result of a growing dependence on this increasing food supply. There is no other single thread of development that can be followed so continuously throughout all our history, and none which bears so constant a cause-and-effect relation to every phase of our progress in civilization. When we trace down from Paleolithic times the genealogy of that heap of pure white flour in the mixing bowl, we are tracing the story of how man performed the most vital of all life functions, on which even the perpetuation of the race itself depended in innumerable crises — the story of how he got his daily bread; and of how, in insuring an ampler and a better supply of that daily bread, he drew nearer and nearer to becoming that master of nature he still aspires to be.

For bread was the next great invention, after the pounding and sifting of the seeds. Women undoubtedly carried the torch of progress here, for men were still stalking wild game. Some found, perhaps accidentally, that the meal was better if it was not only ground but moistened before putting it in the mouth; then that heating the moistened mess — probably spread on a hot stone — brought out the flavor and made it more palatable; and at last someone was careless, left the mess near the fire too long, and found that she had a hard, flat, but tasty cake on her hands. Bread had come into the world.

It was poor stuff at first (Oval, Chapter I). Hard on the outside and sodden within, dark, unraised, thin and meager-sized, burnt, liberally infused with dirt from the seeds and grit from the stones, it was made of a thickish meal rather than a flour. But these early loaves, if we can call them that, represented a modest triumph of patient, clumsy, but sequential labor. They were man's first elaborately processed food, the end of an orderly sequence of gathering, grinding, sifting, and baking. They exerted a powerful force, tending to change their maker's way of life, to domesticate him.

Few human groups have ever been completely mobile. Even the earliest hunters, like the monkeys before them, had homes of a sort — caves to which they returned, shelters against the storm, windbreaks. But rove the hunter must. A very few hunters can destroy the game supply of an area faster than it procreates, and game quickly learns to flee from the neighborhood of hunters. A supply of cereal grains, and then of bread, in time became an indispensable supplement to a meat diet, and a welcome one: the grains made it possible to tarry longer in one place. The family didn't have to leave its familiar, warm, smelly shelter quite so soon as when game alone was depended on, didn't have to venture out in search of a new home and a new hunting ground.

Men found this food supply so good, with all its faults, that somewhere, someone began to tend the wild grass on which the grains grew. We say men, but it probably was the work of women again. While the men were away hunting, the women began to clear the ground around the grass, and to guard it against robber birds and animals, and human marauders from other groups.

For the most part these first tenders could only watch and wait and protect. The dangers besetting the growing grains were greater and more mysterious than anyone's understanding could grasp. Sometimes the plants bore badly or not at all in spite of the tenders' utmost care. They groped for answers to the questions that troubled them, attempting to discover how the mysterious forces of nature could be made to serve them more dependably.

From tending grasses to planting their seeds. In someone's mind the gap between one year's harvest and the young plant of the next was bridged. From planting the seeds in a space already free of heavy growths, repeatedly until the land was worn out, to the clearing of new areas in which to plant them. This meant forward planning over more than a single season, and the development of judgment as to potentially fertile areas. From this it was a step to nomadic agriculture, in which the little working group followed the plants to new areas as the old were exhausted. This ultimately meant continent-wide migrations, following the fertile wind-deposited loess wherever it might lead.

Step by stumbling step, progress was made. From simple dependence on nature's soils to their more careful preparation, including planned enrichment by animal manures (for the animals were coming under the sway of man too). From the digging stick and the primitive hoe to the plow in all its many forms. From the use of man's own strength alone, to reliance on such animals as the ox. From the dragged load to the wheel, that circle of opportunity.

In time men graduated from the indiscriminate planting of wild seeds, to make a considered choice of those found to be the best—to the beginning, that is, of domesticated strains. And then these men began to extend their agriculture into new regions, pushing out from those where the grains naturally flourished into others less favorable, and there by drainage or irrigation and cultivation creating a man-made fertility.

And all this advance was made profitable, and therefore possible, by improved methods of processing the harvested grain for food. To grind the seeds, man turned from his own hands and the rocks he could pick up, to stones he could shape. From simple pounder-rubbers which beat and bruised the grain any which way, he went on to artfully adapted upper and nether stones which made use of controlled motions in the work of opening up the seed. He developed the mortar and pestle and the still more skillfully constructed saddlestone or metate, known wherever grains were cultivated—an instrument completely specialized to milling. As time passed he accumulated an ever increasing family of milling tools, ever more definitely formed to the purpose, employing ever more precise motions, forming parts of an ever increasing and ever more subdivided series of progressive acts, and using ever widening sources of power: a woman's forearm, the whole arm and upper part of a woman's body, the entire body of a man (for in time milling needed a man's strength), the life-energy of slaves, the strength of domesticated animals, and eventually, in classical times, the energy of water and later the even more impalpable energy of the winds; until, in modern times, first steam and then electricity were induced to drive the intricate devices of a completely mechanized, scientifically controlled milling process. All this evolutionary progress, to give man his daily bread, of better quality, in more ample quantities.

Simultaneously, these grain-raisers and grain-grinders advanced from isolated little family groups and tribes through agricultural communities on to cities and even the great ancient empires — built one and all in close dependence on the grains. The grains led them along the road from savagery and barbarism to civilization; from a life whose waking hours were almost completely devoted to the food quest, to the many-sided, variously organized activities of the lands where cheap and plentiful bread makes possible a free, diversified, democratic life.

Compared with the whole history of the race, it is not a very long story. There have been men on earth for a prodigious time, but the artificial breaking up of cereal grain seeds to prepare them for food was first practiced only some sixty to eighty thousand years ago. Agriculture had its beginnings much later, perhaps no more than eight or nine thousand years ago.

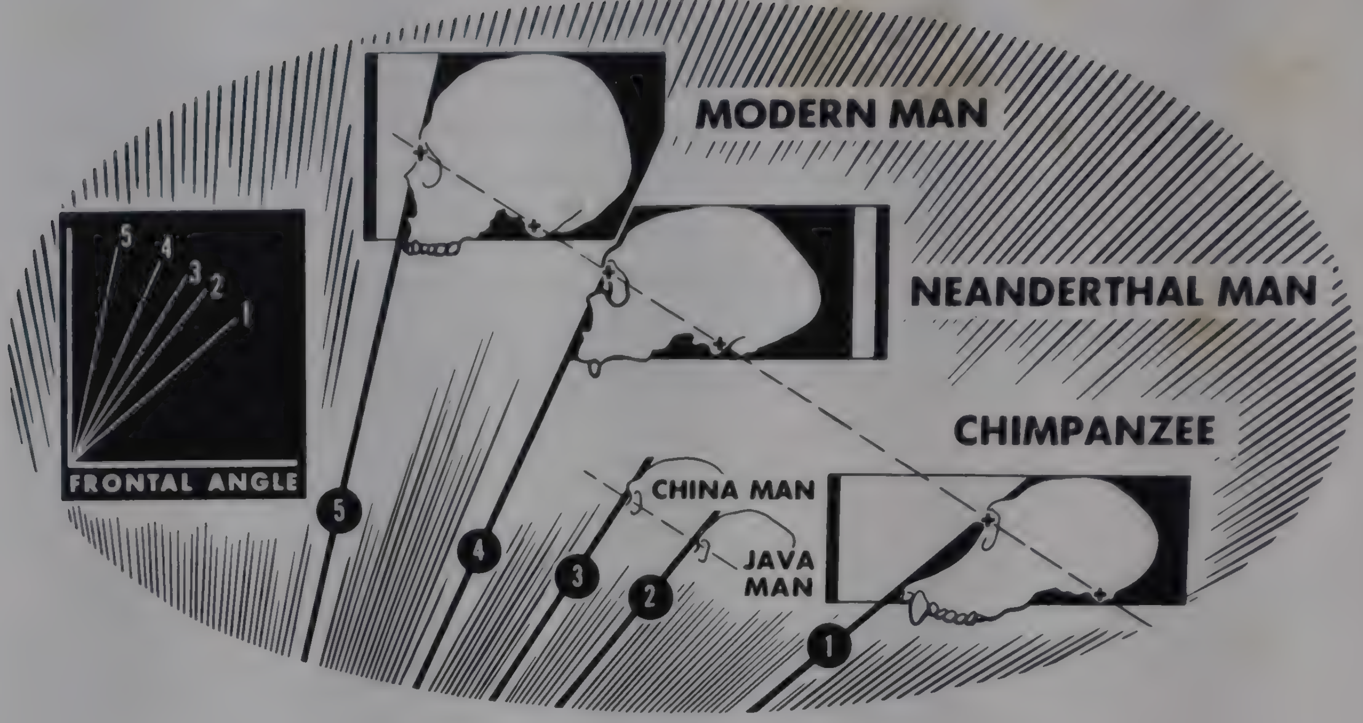
Of man's hour on earth, fifty-five minutes had passed before milling began. Agriculture was invented less than a minute ago. The whole of recorded history is crowded into about one per cent of the race's total life span on earth, a mere thirty seconds or so of man's hour.

We of the West have given our particular species of man a flattering scientific nickname: *Homo sapiens*, perceptive or understanding man, the animal possessed of knowledge or wisdom, the wise guy. The term reflects our satisfaction with a most important aspect of our nature. But whatever sapience we have today is not so much an original endowment as an achievement, and it isn't full-grown even yet, not even in the best of us; it has a future as well as a past.

The thread we shall follow in tracing the history of milling leads us along this line of the development of man's intellectual powers. This isn't surprising. Our tools and machines are like a skeleton of the life they make possible. They show its structure. They are to that life as the anatomy of the human body is to its physiology. In attempting to understand man's tools and machines — the fossils of his actions — we are attempting to understand his very life. These tools are the means of later advancement as well as the results of past achievement. And this is especially true of the tools with which we have supplied one of our few basic needs, the need for food, and particularly the need for that processed food, bread.

We shall confine ourselves, however, to the West — to Europe and adjoining regions and to the New World. We shall exclude the rice-eating peoples in the East, and all primitive peoples except our own historical ancestors and the aboriginal inhabitants of North America. Not that the excluded groups are unimportant, but a line must be drawn somewhere in a subject so vast. We shall concern ourselves only with the stream of development that has led down to the practices of our own time and land. Not completeness, but understanding of our own background, is our aim.

And we shall enlarge that understanding by watching this *Homo sapiens*, from the beginning, earn his daily bread in the sweat of his brow. We shall see him learn new things about his world and himself as he opens up the life-sustaining grains. We shall watch him slowly lift himself by his bootstraps, as he increases his powers by improving the tools he uses to keep himself alive.



CHAPTER II

Diet Makes the Man

> Man is the first animal to grow a limb outside of himself by making tools. This was a great achievement. It takes much less time to make an eolith or sharpen a stake than to grow canines or flatten your tail into a trowel.
>
> —O. G. S. Crawford

MEN of various types were widely spread over the face of the earth for hundreds of thousands of years, and even *Homo sapiens* for many tens of thousands, before systematic food production and processing were undertaken. During the whole of this time a large number of plants suitable for domestication were within man's reach, but his characteristics and his way of life would have to change considerably before these plants would arouse his active interest. So drastic a shift in his attention could only be caused by powerful external forces, and these in time came into play.

Perhaps the most powerful external force acting on man has been climatic change, and climatic changes have been numerous, widespread, and extreme even within our racial life span. Four times during the past 600,000 years there have been great advances of glacial ice and arctic

Chapter head oval. Skulls and frontal angles, showing the altering balance of the skull upon the spinal column.

climate over northern America, Europe, and Asia, at one time pushing the Temperate Zone eight hundred miles south of its present limits, and during one interval of retreat extending it four hundred miles north of its present boundary. Before each advance of the ice, the belt of rain-bearing westerly winds that blow clear around the earth in the North Temperate Zone moved southward, bringing long periods of heavy rainfall to what are now the deserts of southern California and New Mexico, the Sahara, and the Gobi.

These changes from warm to frigid, from arid to moist, although they were spread over tens of thousands of years, had powerful effects not only on the earth's plant life but on its fauna as well. Many new animals appeared during this Pleistocene period, but its chief contribution was ourselves. The genus man is a creature of the Ice Age, and our special type, *Homo sapiens*, a product of its more recent phase, perhaps 100,000 years ago. Recent discoveries show that he was established in a cave near Behshahr in northern Iran, just south of the Caspian, about 75,000 years ago, toward the end of the Third Interglacial period. Thus he made his advent in time to experience the stimulating shocks of some of the later and more severe climatic changes that forced him to make successful adaptations or perish.

We can trace man's advent and his migrations from a few scattered bones that have survived, but principally from the lasting stone tools that he began to make in the very early stages of his career. In the wonderful discoveries in the caves of Choukoutien, in North China, both bones and tools are found in abundance, as well as his hearths and the bones of the animals he ate. From these remains we can reconstruct some of the characteristics and the ways of life of one branch of the human race, *Sinanthropus Pekingensis*, who lived perhaps 350,000 years ago, during the long Second Interglacial period.

Here we have a creature who measured up to the basic qualifications of man: he not only used but made tools; he not only used but, probably, made fire; there is evidence that he was capable of uttering sounds to convey intended meanings. And all of these abilities are connected with, even direct consequences of, the fact that he had long ago abandoned simian food habits in favor of a diet characteristic of man. In that he was primarily a meat-eater, early man differed radically not only from his simian predecessors, and modern simians, but also from all civilized peoples from the beginning of recorded history and indeed from all primitives of today except those living in arctic regions. And at the start of his career it was this meat diet that made a man of him.

All wild monkeys live largely on fruits and the leafy parts of plants. Protein foods—eggs and occasionally small animals—form a very minor part of their diet, and so do cereals and seeds. Consequently monkeys are bound to the tropics, since nowhere else can they find this kind of subsistence throughout the year. Those monkey packs that several million years ago left their original habitat in the Siwalik Hills, south of the Himalayas, and followed the receding tropics into southeastern Asia and central Africa, had no need to change their diet or their habits, and they remained simian. Their descendants exist as the large primates of those regions today.

But there were others who ventured over the great connected land masses into the temperate, sometimes even frigid, regions of central Asia, Europe, and northern Africa, and these became the ancestors of man. With the typical food supplies of the tropics no longer available, these first hardy emigrants were forced to adapt themselves to the conditions of the grasslands they invaded: fruit and edible foliage were scarce, they had little knowledge of the cereal grains, but animals were plentiful. Those who survived did so because they became hunters and meat-eaters.

But the simian ancestors of man were not physically equipped for hunting: they lacked the fangs and lethal claws of other carnivorous animals. Nor did primitive man develop this type of equipment. Instead he survived by developing his ingenuity, and with it that most marvelous and versatile of all instruments, his five-fingered hand. The destiny of the human race lay in the fact that a man's hand is not an effective weapon in itself: it requires, as Spengler has said, "a weapon to become itself a weapon." In order to hunt successfully, man was forced to become a toolmaker, and in that capacity he began a career that by this time has given him a substantial degree of mastery over his physical environment.

From his earliest traces, man's tools and bones are found in association with the bones of the animals he ate. The necessity of assimilating the nitrogen that can be obtained only from plants or the meat of plant-eaters led him instinctively to prefer herbivorous animals, and he supplied his vitamin needs by eating the partly digested contents of these animals' stomachs. There is no evidence that food was stored for future use. Life was literally a hand-to-mouth affair: but there were always tools to help the hand.

In the course of the dietary change a distinctly human social pattern was brought into existence. Among monkeys, all members of the group except the very young engage in an almost continuous search for food. Among the earliest human beings, the adult males hunted for the group, women did the home work and cared for the young. Here was the beginning both of the division of labor and of the social differentiation of the sexes. A male-dominated order slowly came into being.

This dietary change also had its influence on man's developing physical structure. In all monkeys the jaw dominates the skull, since their jaws and jaw muscles are adapted to the heavy and prolonged chewing of the tough cellulose vegetation that forms so large a part of their diet. To balance this jaw structure, the skulls of apes are enlarged toward the rear, rather than at the top and toward the front. As a consequence the skull is balanced on the spinal column in a way that makes an upright posture difficult.

Meat is largely protein and fat, and even when raw requires much less chewing than heavy cellulose. By a process of natural selection, the jaws of evolving man therefore began to recede, and the jaw muscles diminished in size, freeing more space inside the skull. The balance of the skull was altered, with a rise in its height and an increase in its frontal areas. This made possible the development of new frontal sections of the brain, capable of higher intellectual processes (Oval, Chapter II). The different balance of the skull altered its attachment to the spinal column. Man was able to stand upright, his eyes became the most important of his five senses. He took the first steps toward becoming a keen and contemplative observer of the world around him.

At some very early period, perhaps with *Sinanthropus* and certainly in Europe by Acheulean times, 200,000 years ago, the hunters began to cook their meat – and meat alone – in their fires. Whole carcasses or great hunks of meat were thrown onto the fire, after the manner of the Homeric Greeks and many primitives today; though burnt on the outside, these roasts were hardly warm at the center. But even this much cooking tends to break up the tougher parts of the meat, and performs the first stages of the macerating and digestive processes before the food is taken into the mouth. The jaws and their muscles diminished still further in size, and man became more than ever a highbrow, with a larger, more vaulted skull, walking still more erectly. The added cranial capacity was filled out with grey matter through the necessity which the solving of his many problems, and especially the making of his simple but ingenious stone tools, imposed.

Though primarily a meat-eater, early man never entirely ceased eating plant foods when they were available. Although he even condescended to the seeds on occasion, it was not easy to separate the nutritious hearts of the grains from their indigestible coatings, so long as he had only his teeth and tongue to work with, and we can understand that the cereal grains were not popular at this time. They probably were eaten more by the apes than by early man.

Perhaps 20,000 years ago, however, as the last of the three cold phases of the last glacial period slowly drew to a close, man in Europe, and no doubt elsewhere, was confronted with a crisis. This was no new thing. Each glacial period as it arrived and ended had presented crises of the first order. As the glaciers advanced, some men had retreated to the caves and learned to hunt the new arctic animals that appeared with the ice. Some had retreated from Europe into more favorable climates in Africa or the Near East. As the ice withdrew in the intervening warm periods, some men had migrated with the animals as they moved northward, or they had been able to live on the new, more tropical fauna as it arrived. In all cases, they remained primarily hunters.

But by 20,000 years ago, a more advanced race of men reacted to the current crisis in a new way. By that time, *Homo sapiens* had reached a stage of mental development where the powerful impact of climatic change could be a stimulus, not to mere submission, but to a change in his own habits and way of life, creating urgent new needs. The large mammals were becoming too scarce to sustain the human hunter. All right, instead of meekly trekking off in search of new lands of easy abundance, with all the labor, hardship, and loss of life these migrations must entail, he would stand his ground — literally his own ground — and fight it out with nature there.

Not that he reasoned out his course of action in these terms, but under the influence of growing self-confidence, that is what he did. Also not everyone followed this line, and it was not a quick shift; but there were enough hardy souls to establish firmly, in time, a new dietary habit and a new way of life. And this proved so successful that it spread until it was the rule over large areas, and enabled men to live in regions that before had been uninhabitable.

As a meat diet had made man human, the second great change in his eating habits started him directly on the road to civilization.

He became a food-gatherer as well as a hunter. He continued to catch and kill such animals as he could, large or small, but he supplemented his meat diet increasingly with roots and tubers, fish and shellfish, fungi, nuts and acorns, green vegetables; even, in time, with those difficult-to-manage seeds he had tried so often before with such little satisfaction.

This was no reversion to a simian diet: he would use his ingenuity, his tools, and his command of fire to reduce refractory plant foods, such as the acorns, roots, and grains, to the state of edibility he now demanded. It would mean the formation of new habits, the making of new and more specialized tools, the learning of new arts and techniques, a vast expansion of ingenuity, knowledge, and capacities. But man, the toolmaker, had reached a point where he was equal to the challenge.

The change is not to be explained by any obvious attractiveness in the raw materials of the new diet. Quite the contrary — they presented many difficulties. All the familiar food plants of today are the result of countless generations of cultivation. Even as late as the eighteenth century, the carrot was a meager, unappetizing, woody root. The apples of the Lake Dwellers were smaller than wild crab apples, and tasted probably at least as sour. Potatoes and maize, or Indian corn, were unknown outside America. Wild einkorn, one of the ancestors of our wheat, and teosinte, a hypothetical ancestor of maize, were poor enough beginnings for master grains.

Then too, many of the plants commonly depended on by primitive food-gatherers were actually unpleasant to the taste, or even poisonous, until elaborately treated. Acorns had to be freed from their tannic acid, manioc from its deadly hydrocyanic acid, the grains from their hard outer cellulose matter and their only slightly less indigestible inner coatings. Many of the foodstuffs of early man are acrid, bitter, downright nauseating, or insipid to our taste today.

The food-gatherer was forced to take the plants as he found them and process them into something he could use. By what stages he advanced in these arts we do not know. Which came first: Washing or soaking a plant in water to get rid of its bitterness or some other undesirable attribute? Sun-drying it, as is still done sometimes with sweet corn or fruit? Burying it or hanging it to decompose? Allowing it to ferment – primitive man had an inordinate love of sour things, as we still love sauerkraut and pickles? Smoking it over the cave fire? Cooking it? Grinding or pounding the hard foods to make them assimilable?

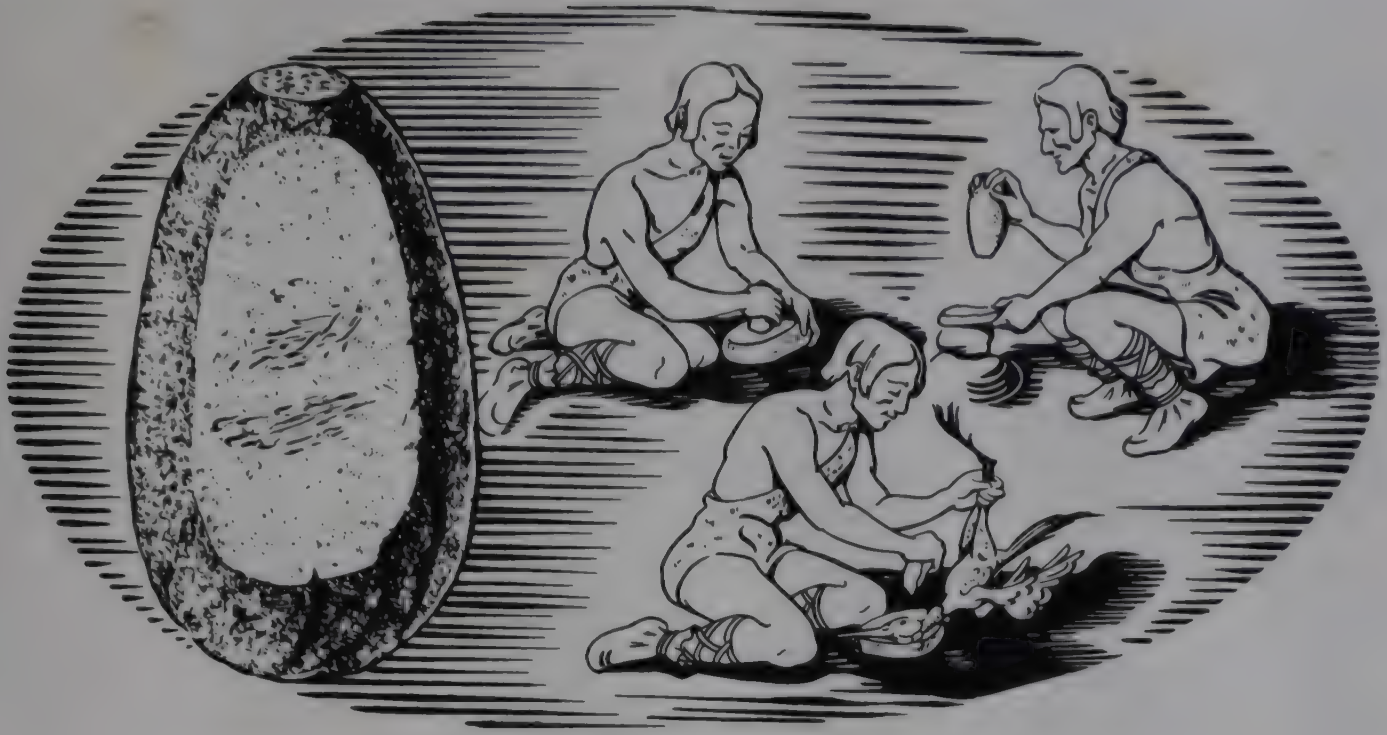
A number of these processes would have to become common practice before plant foods could outstrip meat in the food-gatherer's diet. And, in addition, means would have to be found to ensure an adequate, year-round supply of the plant foods. It would be necessary to learn to plan and carry out orderly routines, however simple. Since most Temperate Zone plants yield only an annual crop, a beginning had to be made at general planning of the group life and, reluctantly, at some small degree of conservation and self-restraint. In the course of this effort, nature itself became the subject of closer scrutiny. The sequence of growth, fruition, death, and rebirth in the plant world came to have profound interest, and the relation of this cycle to the cycle of the seasons, the movement of the heavenly bodies, and the state of the weather began to be observed. A body of beliefs, partly mystical and partly practical, was slowly formulated to become the basis of future religions and to play a great role in the beginnings of agriculture. For early man learned to cultivate the plants he needed most, and his foot was firmly on the threshold of civilization. He entered vistas of advancement we are still exploring.

In this transition the cereal grains became the final, decisive factor. Of all plant foods, they presented the most stimulating challenge to a creature able to cope with it: they were the most difficult of all to deal with, but they were the most rewarding if successfully handled. Because of the first fact, they were not dominant dietetically until late in the transition period; because of the second, their influence on the human race was swift and drastic once they were mastered.

Meat, fruit, and vegetables are all extremely perishable, unless subjected to the elaborate processing which has been perfected only in recent generations. But if the cereal grains are kept dry, they retain their nutritive value and their taste unimpaired almost indefinitely. And as an energy builder, they rank among the highest of all foodstuffs. These two characteristics, that they did not spoil and that they were potent quellers of hunger, led men in time to concentrate on grains as the mainstay of their diet, a food that could be depended on to tide them over when all else failed. And they led him to form the habits, develop the arts, organize the societies which made possible a year-round supply of grain food in a palatable form.

To master the grains, first of all, sure and dependable ways of isolating their nutritive centers from their repellent sheaths had to be perfected, through the invention of steadily more effective implements; the art of baking the resulting meal into digestible bread had to be learned; and, to make this effort of processing worth while, little patches of wild grass had to be transformed into the vast, waving grain fields of Mesopotamia, Egypt, and central Europe, again through a steady proliferation of more and more complex tools.

It is no exaggeration to say that the solving of these difficult problems has done more to set the pace of human advancement and the pattern of human life than any other influence.



CHAPTER III

The Grinding of Wild Grains Begins

All beginnings are difficult.
—Aristotle

The first hundred years are the hardest.
—*Homo sapiens*

So LONG as chance patches of wild grasses were the only source of grains, they would not bulk large enough in human diet to make their processing a matter of primary concern; other arts would advance much more rapidly. But as the transition to a food-gatherer's diet proceeded, we can see a very gradual improvement in grinding implements, whether or not they were made primarily for use on grains; and after a mere ten or twelve thousand years—a short time for those days—we find that man had made not only grinding but reaping tools, which indicates that the cereal grasses had become important in his estimation. By that time he undoubtedly was tending the wild grasses, else why should he have given such attention to these tools? And in the tools themselves we can see registered the gradual expansion of his mental powers and his ability to deal with his environment.

Tools of a form adapted to grinding and rubbing existed long before

Chapter head oval. Aurignacian combination stone from La Combe, France.

the transition period began, and are found wherever plant foods played any part in human diet. Everywhere they followed the same obvious pattern of flat-surfaced stones used together in pairs for pounding and rubbing, developing in time into crude prototypes of later devices. Whenever primitive men have been confronted by similar problems they seem to have worked out very similar solutions.

Out of the thousands of early grinding stones that have been found, we need to examine only a few typical specimens. The earliest date from Aurignacian times, about 75,000 years ago. Some are simple, roundish stones, perhaps an inch and a quarter thick, with a flat working surface measuring three or four inches across. Held in the palm of the hand, they would be worked against another stone in either an up-and-down or generally back-and-forth and round-about motion. An unusually elaborate example of such a stone is shown in the oval heading of this chapter. It was really a crude tool kit, since it was clearly used as a hammerstone, a chopping block or anvil, and a rubbingstone. As a rubber, it could have been used to grind bones and pigments, and it could also have been used to grind grains; but if the last, it would have done the job as crudely and wastefully as the simpler specimens. Grain-grinding when well done is a gradual process: the particles must somehow be *contained* while the meal

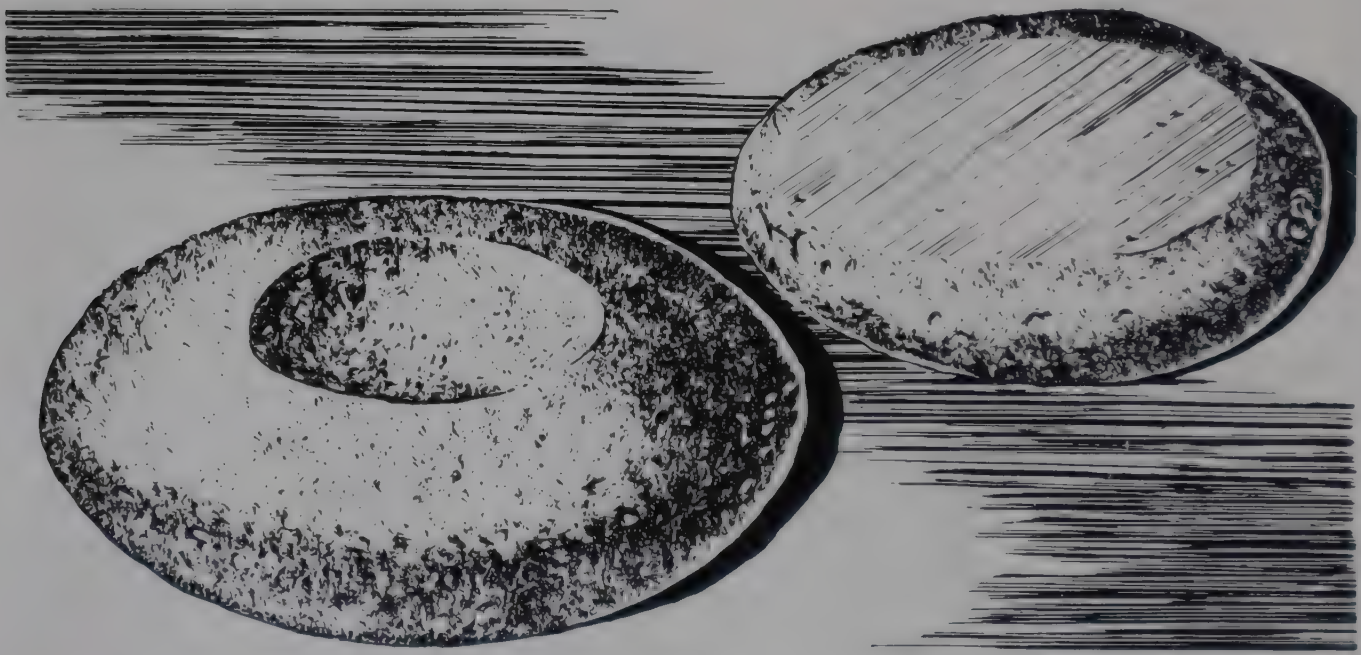


Figure 2. Magdalenian implements suitable for grinding, dating from about 25,000 years ago, which were found in caves in the valley of the Vézère, France. The rubbingstone, from La Madeleine, type station of the Magdalenian culture, is a water-shaped granite pebble a little under 3 inches wide. Though clearly specialized for rubbing, it does not represent so significant an advance as the mortar-like form, which measures about 8 inches long and is from Laugerie Basse. Some of these shapes, though shallow, have depressions as much as 5½ inches across, which would permit the grinding of small quantities of grain.

is being reduced and separated from the sheaths. No such understanding of the grinding process had been reached by the makers of these tools.

Some 50,000 years later, early in the transition to food-gathering, the Magdalenian men who occupied the famous caves in the valley of the Vézère in France had arrived at a far higher level of craft skill. They did exquisite work in ivory and bone, materials more responsive to delicate craftsmanship than stone, and they chipped many tiny and precise flints. Among their remains are numerous examples of grinding stones, of which those shown in Figure 2 are typical. These are beginning to be specially shaped for their purpose, but not so skillfully as the barbed harpoons, darts, and spears of the same period, a fact showing that hunting and fishing were still dominant in the life pattern.

But the mortar forms are new and mark a distinct advance in the art of grinding. Here we have an implement adapted to retain the substance being pounded, so that a careful, controlled operation could be carried on until a desired degree of fineness had been reached. It is clear that the form was not arrived at accidentally, but was the product of clear intention guiding manual skill, and would only have been made by someone who had learned to appreciate its advantages. No definitely identified pestles have been found, but small stones could have been picked up in any stream or gravel bed to serve the purpose. In these mortars we find the first tentative appearance of a form and technique that have been developed and retained in use, in a wide variety of applications, until today.

Some specimens of both rubbingstones and mortars are stained with red ochre, a pigment ground by the Magdalenians, but many show no trace of color. There is no certain proof that they were used for grinding grains, but everything about them indicates that they were domestic implements. Here for the first time pounding and rubbing were differentiated as processes used together in the home. It was in the home that the milling of grains would be done for many thousands of years, and here we see that the principal grinding processes it would employ throughout the greater part of that time had already been invented.

Our belief that the transition to a much greater dependence on plant foods was under way in these Magdalenian times has substantial supporting evidence. In this period the cave drawings first reveal an interest in plant life, and for the first time cooking was being done in a way suitable for plant foods, which require protection from direct contact with fire. Although the Magdalenians made no pottery, their caves contain hollowed stones which bear unmistakable marks of fire and could have been used for boiling or stewing their contents. There are also crude underground ovens, holes in which fires were built to heat the surrounding sand and rocks. After the fire was drawn, this heat would have cooked any food packed in the hole. Evidently the Magdalenians were interested in cooking something besides meat, for the preparation of which these newfangled devices of hollowed cooking stones and ovens wouldn't have been necessary.

A time of change is also indicated by the fact that men were suffering from vitamin deficiencies. Their skeletons show that some had had rickets, a vitamin-deficiency disease, in their infancy, and dental decay in their old age. The rickets may have been due in part to their life in dark caves, too much out of the sun; but there was an increasing scarcity of large herbivorous animals, whose stomach contents had previously supplied the vitamin needs of the hunters.

All these facts support a conviction that the Magdalenians in the early postglacial period, some 20,000 years ago, had begun to supplement their meat diet with a more extensive use of plant foods, with the cereal grains as yet playing only a minor role in their menu. They had made implements whereby small quantities of grain could be milled, and probably were being milled. But if these grains had been important to them, their skills certainly would have been equal to developing means of processing the meal more efficiently and on a larger scale than was possible with any of the implements we have yet found.

After a lapse of 8,000 years, we find evidence of a growing preoccupation with the grains, in Azilian times in Europe. This culture produced stones in pairs more definitely adapted in size and shape to grain-grinding (Figure 3). From this same period also came small rectangular flints, less than an inch long and often only a quarter of an inch wide, with minute teeth in the cutting edge. These are often called "saws" by the archeologist, but it is almost incredible that such tiny implements could have been used alone, held in the fingers. They strongly resemble the sickle blades of Figure 8, which are known to have been set end-to-end in handles for use in cutting grain. If the Azilians were not using sickles, they certainly had developed their prototypes. With compound tools like these pounder-rubbers and at least the makings of sickles, primitive man was getting himself ready for undertaking the cultivation of grains.

In America, peculiarly favorable conditions brought about a high development of domestic milling in advance of and without regard to agriculture. Asia is the native home of wheat, barley, oats, rice, millet, and all other true cereals except maize, or Indian corn. But the Europe of primitive man was not notably rich in edible plants. America by contrast had an abundance of edible seeds, nuts, fruits, beans, roots, and tubers, many of them unknown in Europe until after Columbus' voyages. Especially southern California, our Southwest, Mexico, and the regions centering in Peru were botanical paradises during the well-watered years of the pluvial, or rainy period, coinciding with the most recent glacial advance.

The first men arrived in these lands during this period of heavy rainfall and, of course, were hunters. But almost at once they began to supplement

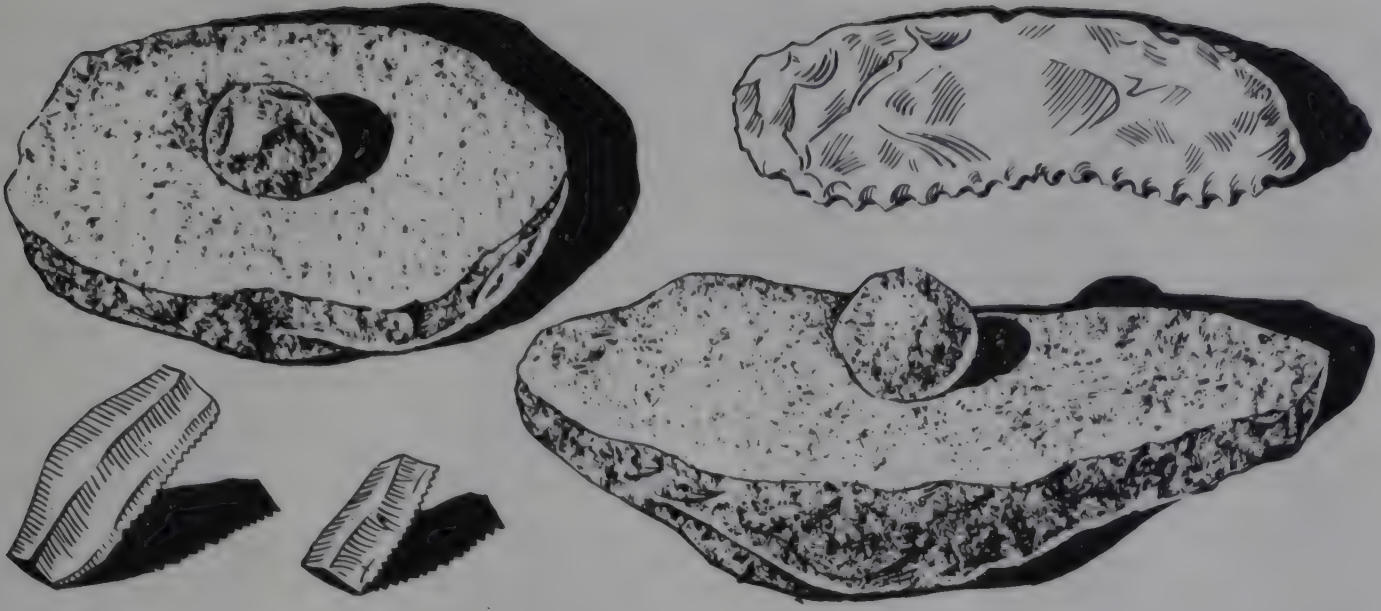


Figure 3. At the left, a pounder-rubber from Mas d'Azil, southern France, type station of the Azilian culture, which was probably used for grinding grain. Below, small-edged flints, called "saws" by the archeologist, which could have been grouped in sickle blades for cutting grain. These implements date from about 10000 B.C. At the right, for comparison, a grain grinder and sickle-like blade from the Danish Maglemose food-gathering period, a later phase of the same general culture period. The pounder-rubbers are about one-quarter full size; the "saws" are approximately full size.

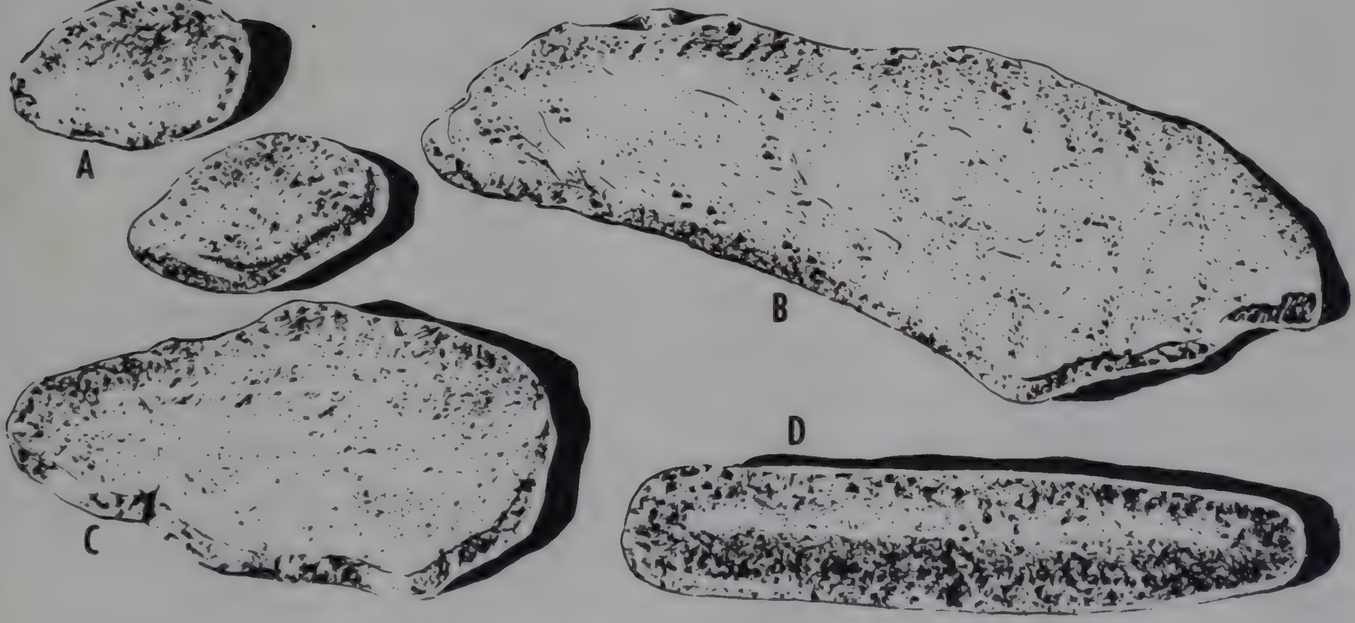


Figure 4. Pounder-rubbers from Pinto Basin, Riverside County, California, which were found along the shore line of a now dry lake. They date from about 8000 B.C. A, upper stones. B, large lower stone, about 15 inches long. C, small lower stone, about 8 inches long. D, pestle, about 12 inches long. The top stones usually have two working surfaces, although they seldom are more than partially shaped, if at all. Usage has produced a slight oval depression in most of the lower stones.

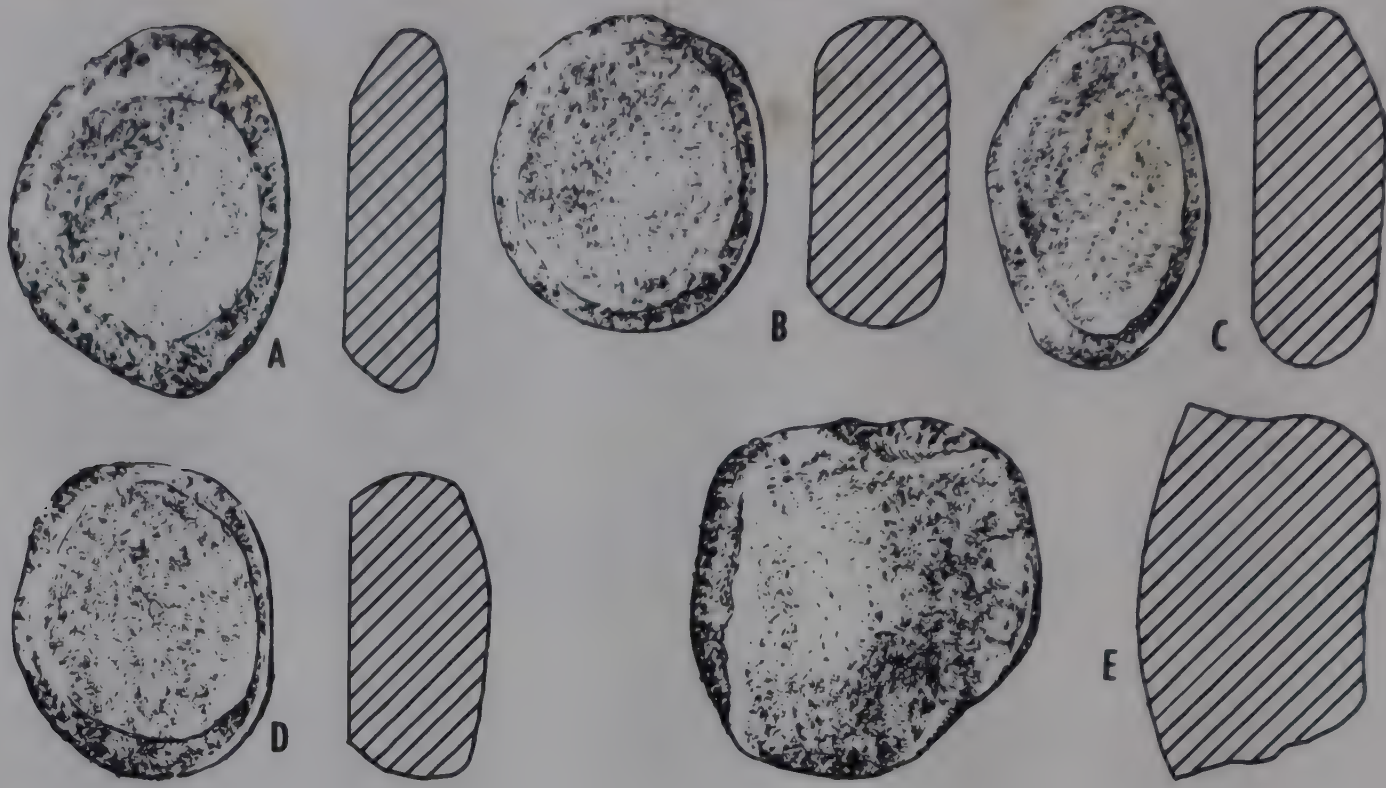


Figure 5. Upper rubber stones (manos) from the Cochise culture, Arizona, shown from above and in cross section. A and B, from Sulphur Springs stage, probably before 8000 B.C. C to E, from Chiricahua stage, from before 3000 B.C. Note the insignificant differences in form over thousands of years.

their meat diet with the many plant foods that could be had for the gathering. Their acorns, beans, roots, tubers, and the dried fish they liked were improved by pounding and grinding, and some of the tribes became skillful millers.

The earliest traces of man in this southwest region date from about 15,000 years ago and are found on the shores of a body of water, once great but now long vanished, which geologists call Lake Mohave. The nearby Pinto Basin was settled some 5,000 years later. At some time during the interval between the two settlements these people took seriously to grinding their foods. No indubitable pounder-rubbers have been found on the Mohave beach, although there are hammerstones which are thought to have been used in food processing. But on the surface in the Pinto Basin sites, along with many other implements, more than a score each of top and bottom stones of pounder-rubber combinations have been found (Figure 4). Their small number, small size, and crude appearance, plus an abundance of flaked implements, indicate that while the Pinto Basin people were grinding some foods, they still depended very largely on a meat diet.

This was also true at first of the people who inhabited another once fertile, now dry region that stretches from Arizona, south of Tucson, eastward into New Mexico. Here a series of cultures flourished in unbroken sequence from a time contemporary with the Pinto Basin people up to about 2,500 years ago, a most remarkable continuity. Pounder-rubbers were in use here from the beginning and changed very gradually during the long span of millennia. At first almost all the base stones were flat and the upper stones were not highly worked, only a few being flat on both sides (Figure 5). At this time, there were no mortar-like forms. Later the stones became more regular in shape, and slowly began to look like the metate-mano combination so well known in later periods of American archeology —the metate (old Mexican Nahuatl *metlatl*) being the under stone and the mano the upper or "manual" stone of a pair whose forms have been specially adapted to each other. In the last period, too, mortar-pestle forms appeared.

Most interesting from our standpoint are the people who lived among the luxuriant oak groves of the Santa Barbara region, beside great rivers that are now, 10,000 years later, only deep and wide arroyos. Their life was peaceful and prosperous, and they lived well, principally on fish and the abundant acorns of their oak groves. While they had few weapons, they made many implements for grinding the acorns into meal. As always when a need is urgent, these grinding tools were rapidly improved in efficiency.

Two examples of these combination stones typical of different stages of development are shown in Figure 6. Early under stones, as in the left-hand example, are heavy and flat, with irregular outline. They measure perhaps 18 inches long and are as much as 6 inches thick, a size ample for grinding a family's meal. The upper stones are also roughly shaped, possibly chosen at random, but with the passing of time they become more regular, with flat sides. This came about in part through use and in part by previous working. The under stone also loses its irregularities and becomes more elliptical, with one end usually shaped to fit between the knees. In addition

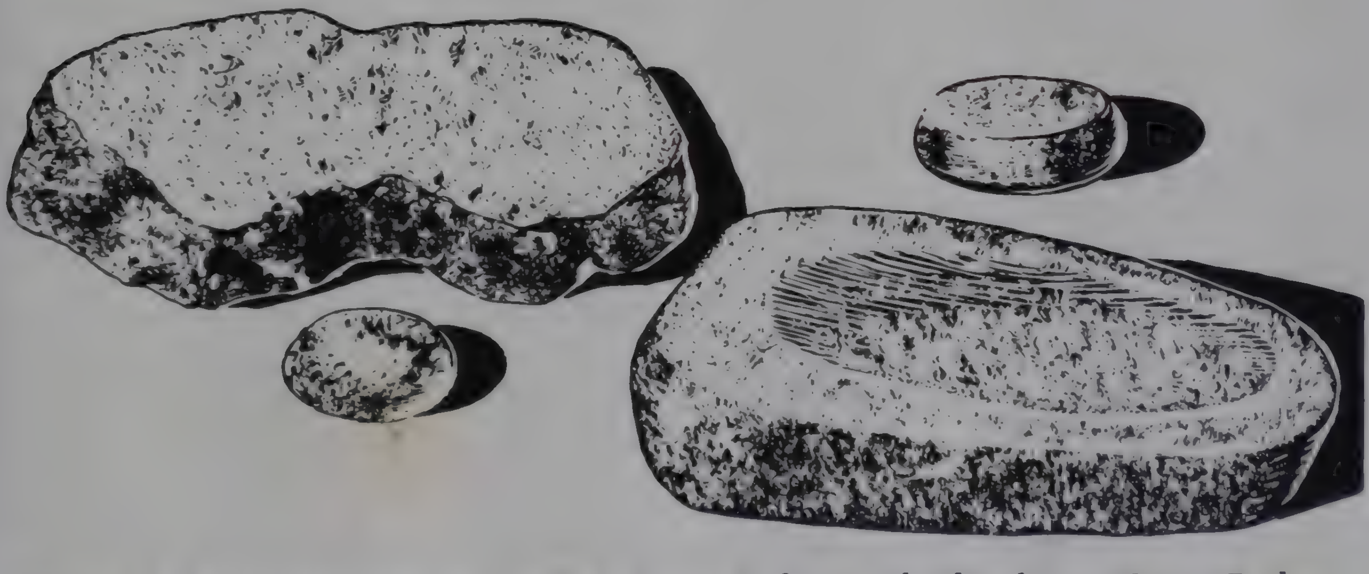
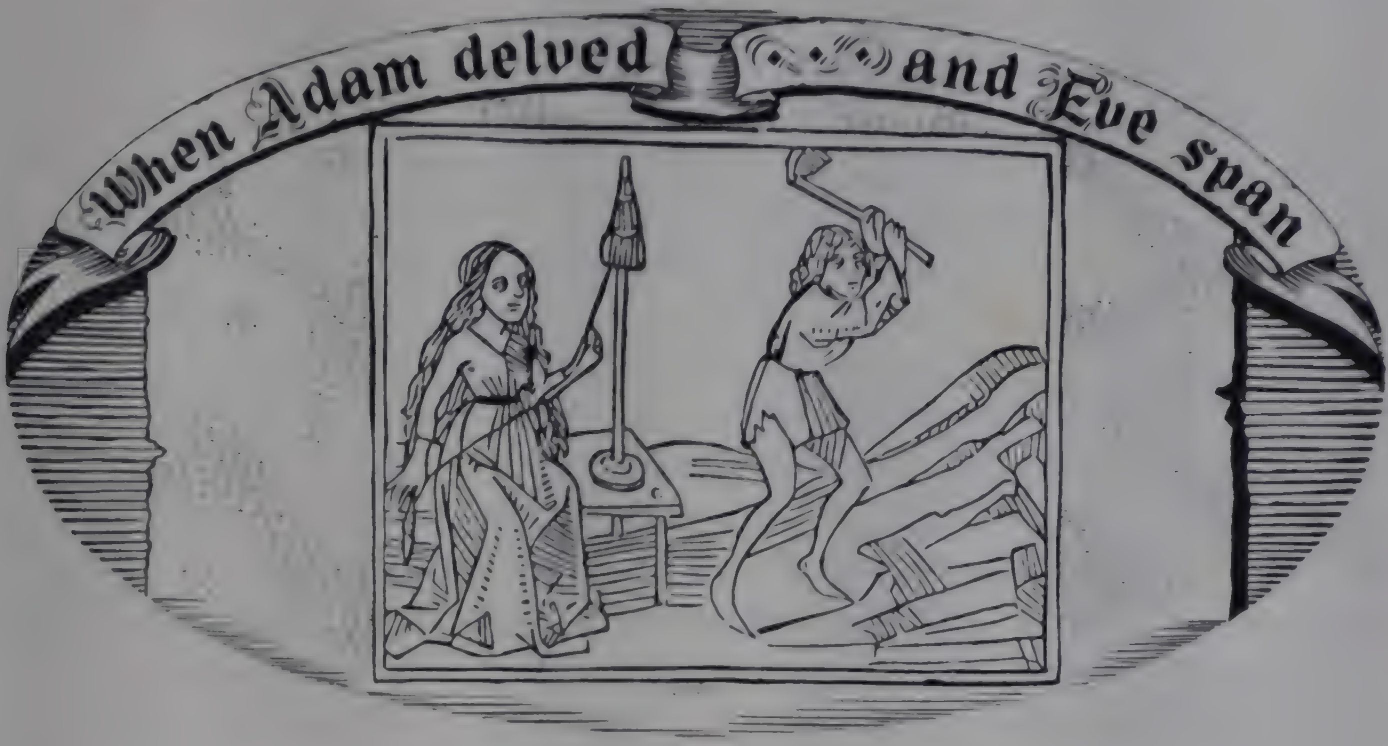


Figure 6. Pounder-rubbers of the Oak Grove Indians, who lived near Santa Barbara, California, about 10,000 years ago. At the left, an early combination, with both stones almost unshaped. At the right, a more developed pair, more like the later metate-mano combination.

a shallow oval hollow gets worn or worked in the upper surface, a useful improvement for containing the meal. These stones may eventually have been used in a slanting position, with the near end supported. The upper stone usually was matched to the lower. Two upper stones are often found near a single lower stone, suggesting, although not proving, that they were sometimes used in pairs, one in each hand, to speed up production. A few of the lower stones show a deeper cavity in the center of the worn spot, and toward the end of the period we find crude mortars and pestles, as well as anticipations of the metate-mano form.

The Oak Grove stones certainly would do a better job of grinding than the Azilian stones of Europe from about the same period. It is clear that these early Californians had the greater incentive to improve their grinding art: long before the beginnings of agriculture in America their milling tools were following the same line of development that later produced the saddlestones of Asia and Europe, when agriculture was practiced on those continents. It is facts like these that have led some to the belief that agriculture in America may be quite as old as in Eurasia.

What became of these Oak Grove people we do not know. Perhaps their peaceful way of life made them an easy prey for better-armed invaders. Probably climatic change had its destructive way with them as with so many other primitive peoples. Human life would not acquire stability, and human progress could not march continuously, until man had accomplished the greatest revolution in all his history – the change from searching for food, whether animal or vegetable, to producing it. All the advancing arts of early food-*gathering* peoples were preparing them, or some of them, to become food-*raising* peoples. And the most important, the determining factor in this great access of control over our environment, was the domestication of cereal grains.


When Adam delved and Eve span

CHAPTER IV

Grain Cultivation Begins

> History celebrates the battlefields whereon we meet our death, but scorns to speak of the plowed fields whereby we thrive; it knows the names of the King's bastards, but cannot tell us the origin of wheat. That is the way of human folly.
>
> —J. Henri Fabre

> Civilization is, as it were, a second flowering of barley, wheat, rice, and Indian corn.
>
> —M. D. C. Crawford

MAN's first home, according to the Book of Genesis, was a garden lying eastward in Eden. There he lived in happy ignorance, feeding freely on the seed grasses and on the tree fruits "which were to him for meat." He was, in fact, a food-gatherer. In neither of the two accounts brought together in the first two chapters of Genesis is there any mention of meat-eating. Even to the animals was given only "every green herb for meat."

After the apple of knowledge had been tasted, however, Adam and Eve were expelled from Eden, and condemned to till the ground—"in the

Chapter head oval. "In the sweat of thy brow shalt thou eat bread." From Anton Sorg's *Almanac* (German, 1476).

sweat of thy brow shalt thou eat bread." Here the myth is explaining something familiar to all who heard it in its original setting – the dependence of agriculture on the mysterious forces that rule the world, its religious and ritualistic associations. Planting had to do with the mystery of life and death, and life again. It was essential, therefore, that these ritual acts be done at the proper time in the proper way. For this, priests – specialists in the proper – became as necessary as farmers. Priests as well as farmers began to accumulate and pigeonhole their practical observations of what would and wouldn't work. A body of canny wisdom was built up, along with a great deal of what may seem to us interpretative nonsense.

The association of agriculture and religion is common to all beginning agricultural societies; but it was especially characteristic of what Breasted called the Fertile Crescent, the region stretching from Egypt up through Palestine and Syria and then down through the Tigris-Euphrates Valley to the Persian Gulf (Figure 7). Somewhere in the Fertile Crescent, which then deserved the adjective far more than it does today, the Garden of Eden was supposed to have flourished, and agriculture undoubtedly first developed. And it was on the borders of this region, too, that pastoral nomadism, the complement of agriculture, also took shape.

Shortly after the expulsion from Eden, we are told that Adam and Eve bore two sons: Cain, the first-born, "a tiller of the ground," and Abel, "a keeper of sheep." The feud between these two, in which Abel died at Cain's hand, is an effort to explain another fact, the hatred and suspicion with which nomadism and agriculture have faced each other throughout their

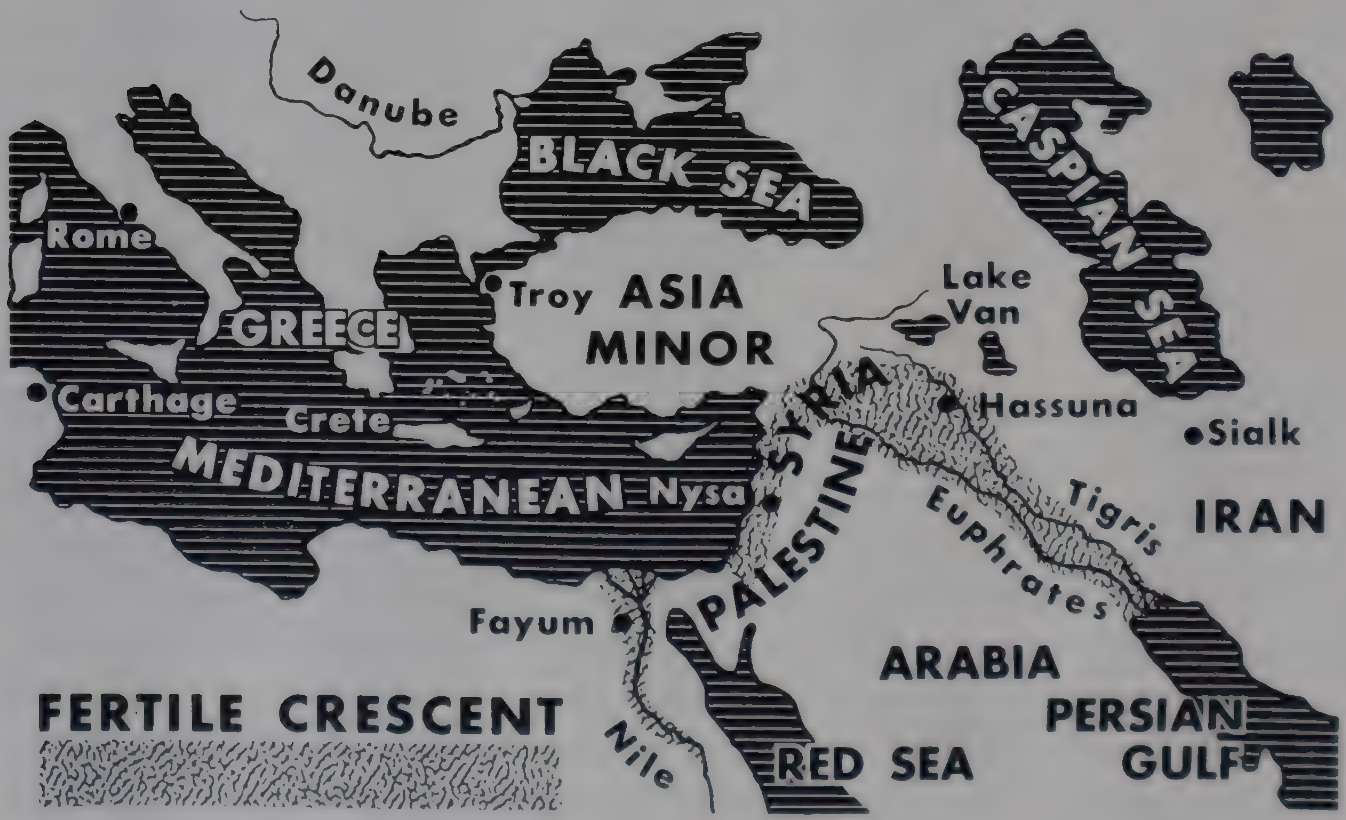

Danube
BLACK SEA
CASPIAN SEA
Rome
GREECE
Troy
ASIA MINOR
Lake Van
Carthage
Crete
SYRIA
Hassuna
Sialk
MEDITERRANEAN
Nysa
PALESTINE
Euphrates
Tigris
IRAN
Fayum
ARABIA
FERTILE CRESCENT
Nile
RED SEA
PERSIAN GULF

Figure 7. The eastern Mediterranean and Near East.

existence; for herdsmen must range in search of pasture, farmers must keep their fields inviolate. It is a conflict we saw flare up in our own country when the cattle ranges of the Great West began to be fenced.

Nomadism and agriculture are both adjustments to the postglacial food crisis, but they differ completely in their psychological outlook. The nomad is fiercely free, yet he lives the simple life of his ancestors and has no occasion to do otherwise; nomads of today live essentially as their forebears did thousands of years ago. The farmer is bound to the soil, but he is engaged in a constant struggle with the elements, the earth, and countless inimical forces of nature: he must progress if he would gain greater ease and comfort. His life is so stable and so productive that it not only permits but demands a more complicated social pattern than nomadism. Thus civilization itself, with its arts and diversified human activities, was the direct and greatest fruit of the cultivation of the soil.

That their civilization was an outgrowth of agriculture was obvious to the Egyptians, as is shown by their story of Osiris and Isis, their first mythic deity-rulers. In the words of the ancient Greek antiquarian Diodorus Siculus, "Isis found out the way to make bread of wheat and barley, which before grew here and there in the fields, amongst other common herbs and grass, and the use of it unknown: and Osiris teaching the way and manner of tillage, and well management of the fruits of the earth, this change of food became grateful . . . He found out the use of the vine and taught others how to plant it and use it."

This happened "near unto Nysa," a place-name which also appears in a Greek agricultural myth; for the *Hymn to Demeter*, the goddess of agriculture, tells us that her daughter Persephone was gathering flowers on the plains of Nysa when she was kidnapped down to the underworld by its ruler Hades. In the finale of the story, Persephone (like the plants) eventually was allowed to spend two thirds of the year on earth and one third underground with Hades. Once more we have a myth accounting for a fact, and indicating that ancient tradition pointed to Nysa as the birthplace of agriculture.

Where, then, is Nysa? Pliny tells us that Nysa is Scythopolis, the modern Beisan, located a few miles south of the Sea of Galilee, west of the Jordan. It was just across that river that Aaronsohn in 1906 found wild barley as well as wild emmer and wild einkorn, the two known wild varieties of wheat. These grains still grow in the wild state in an area that stretches eastward from Asia Minor, Syria, and northern Palestine through northern Iraq, Transcaucasia, and Iran to Afghanistan and Turkestan; and where the wild grains grow we must look for the beginnings of their cultivation. A semi-highland section without dense vegetation and with no more than moderate rainfall would provide favorable conditions for grain growing; and if the region was well inhabited at the time of the last great climatic change and then experienced difficulty with its food supply, the probability would be increased. At the same time, the country should be surrounded by less promising regions — deserts, arid steppes, rough mountains, or the sea — so that the incentive to leave it would be blunted. All these conditions are met in the Syria-Palestine region, the very one mentioned in our myths — Hebrew, Egyptian, Greek; and it is just here that we come on the Natufians, the earliest known culture leaving quantities of implements used to process the grains.

The Natufians lived on the slopes of Mount Carmel, not many miles from Aaronsohn's wild grains. Theirs was a microlithic culture — one, that is, in which the great majority of flint implements are tiny, as small as a half inch long. Ten per cent of their flints are sickle blades, made to be inserted side by side in a grooved handle for mowing grasses; thirteen incomplete bone handles and two complete ones have been found in the region (Figure 8) as well as fragments of mortars and pestles usable for grinding grain. We have very similar sickles from the Fayum, in Egypt, and from Sialk, in north-central Iran. The Fayumian and Sialkian cultures flourished on one or the other side of 5000 B.C., but the high point of the Natufian pattern was reached a few millennia earlier.

The most certain archeological proofs of an established agricultural society include: actual remains of cultivated varieties of grain; pottery, or some means for the storage of grain in quantity; remains of village communities — for permanent settlements began to grow as soon as agriculture

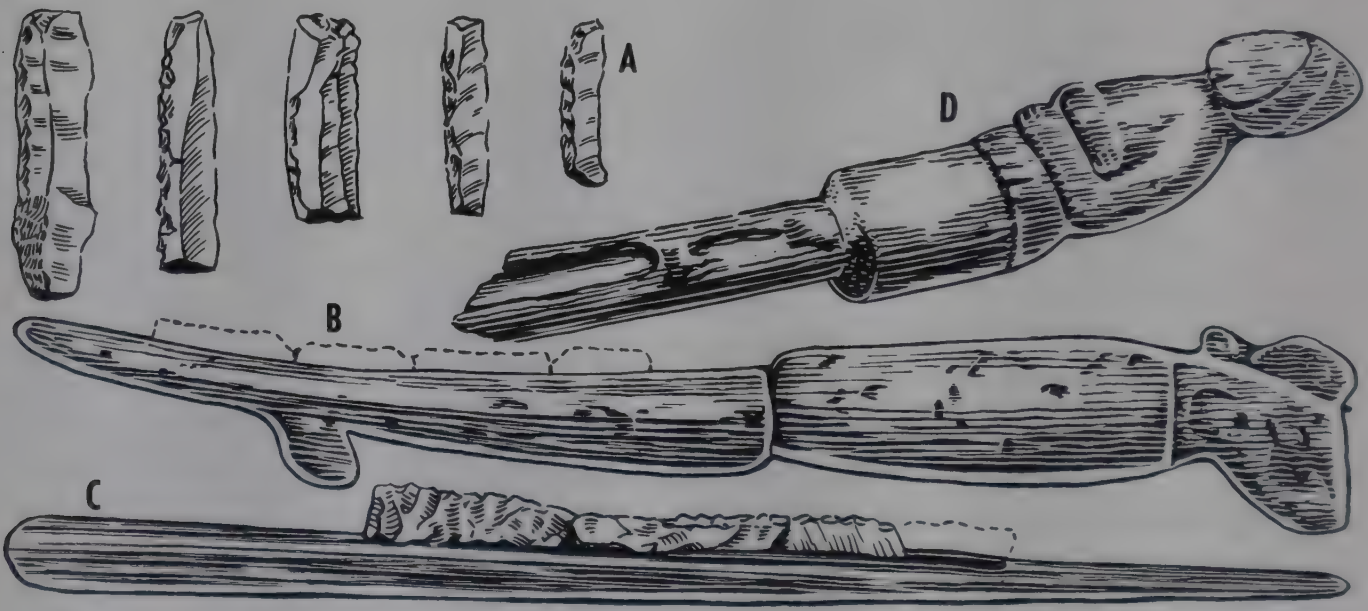


Figure 8. Early sickles and sickle blades, all dating from about 5000 B.C. or considerably earlier. A, Natufian flint blades from Palestine. B, bone sickle handle of the Natufian period from el-Kebara, Palestine. C, wooden sickle with flint blades from Fayum, Egypt. D, portion of bone handle from Sialk, northern Iran. The Natufian handles terminate in a carved animal head, and have a knob of unknown use near the other end, while the handle from Sialk is shaped into a human form.

made it possible to feed them; evidence of religious attitudes centering in the identification of human and plant fertility. But the first beginnings of agriculture must, of course, have been more tentative. In a region where wild grains were plentiful, their cultivation may well have been the natural next step taken by a group possessed of microliths and far enough advanced to combine them in sickles for reaping wild grasses. And evidences of early grain-growing in this, the mythic center of civilization, have been discovered.

Working in the cave Ghar-i-Kamarband, also called Belt Cave, in northern Iran, not many miles south of the eastern end of the Caspian, archeologists within the past few years have revealed not only the existence of agriculture but the background whence in at least one setting it had sprung. More than thirty thousand items of interest recovered from the cave include many flint and bone tools; jewelry made from sea shells, the teeth of animals, jade, and polished stone; primitive baked pottery; and the bones of animals (but no human bones). They permit the identification of three successive patterns of living.

In the earliest of these patterns, the inhabitants of Belt Cave were hunters, principally of the gazelle and wild ox, but also of wild sheep and wild goat. These animals testify to the general dryness of the region. As the first period merged into the second, the inhabitants began to domesticate goats, and thereafter sheep, but only for their meat and skins. Finally, they were milking these animals and shearing the sheep, and had adopted grain agriculture along with pottery making and the use of stone axes; at about the same time or a little later, the pig and ox also were domesticated. Among the finds were microlithic sickle blades coated with a silica patina from the grain stems on which they had been used, as well as sandstone milling stones and mortars. Reports as yet make no mention of the exact species of grain that was grown.

Thanks to nuclear physics, these finds can be accurately dated. So long as plants and animals are alive, they ingest carbon dioxide from the atmosphere, which must contain minute quantities of radioactive carbon 14. When an organism dies, it no longer receives additions to its store of atmospheric carbon, and its carbon 14 slowly disintegrates into ordinary nitrogen, half of a given mass being thus transformed in about 5,568 years. The time that has elapsed since the death of the organism can therefore be calculated in terms of the lowering of the ratio between radioactive and ordinary carbon in the specimen, as compared with the normal ratio obtaining for living things.

By this method, which of course requires the most delicate handling throughout, Belt Cave agriculture has been dated as beginning about 6050 B.C. To show how far ahead the uplands were in this matter of agricultural origins, as compared with regions more definitely within the lower-lying river valleys, the earliest known grain-using, though not necessarily grain-producing, village setting in Iraq, that at Jarmo on the edge of the Kurdish foothills about forty miles from Kirkuk, has been carbon-14-dated only to 4700 B.C. This site apparently lacks not only pottery but hoeing stones, which argues against agriculture, although it is twelve centuries later than Belt Cave.

The likelihood of coming on early instances of agriculture is greatly increased as one moves away from the scenes of its later Near Eastern triumphs in the valley of the Two Rivers, provided that one keeps within the stretch of territory where, even now, the wild grains still grow. As this area is more thoroughly explored, we may confidently expect to find the origins of agriculture pushed ever nearer to the tenth millennium B.C., and therefore also the origins of settled village life, of pottery, of the religion of fertility, and, in fact, of that whole complex which lies behind civilization.

We have evidence now that at Jericho, in a village setting to the south of our Natufians near the northern end of the Dead Sea, there existed a typical sequence of the stages of clay working leading to pottery which may date from 5000 B.C.: pottery only became indispensable for storage and cooking after the grains had become plentiful through cultivation. To the east of our region, at Hassuna, due west from Sialk, thirty grain bins of unbaked clay tempered with straw were found in a village setting of about the same date, together with pounder-rubber stones and even ovens—clay barrels, tipped at an angle, in which fire was kindled, the ashes raked out,

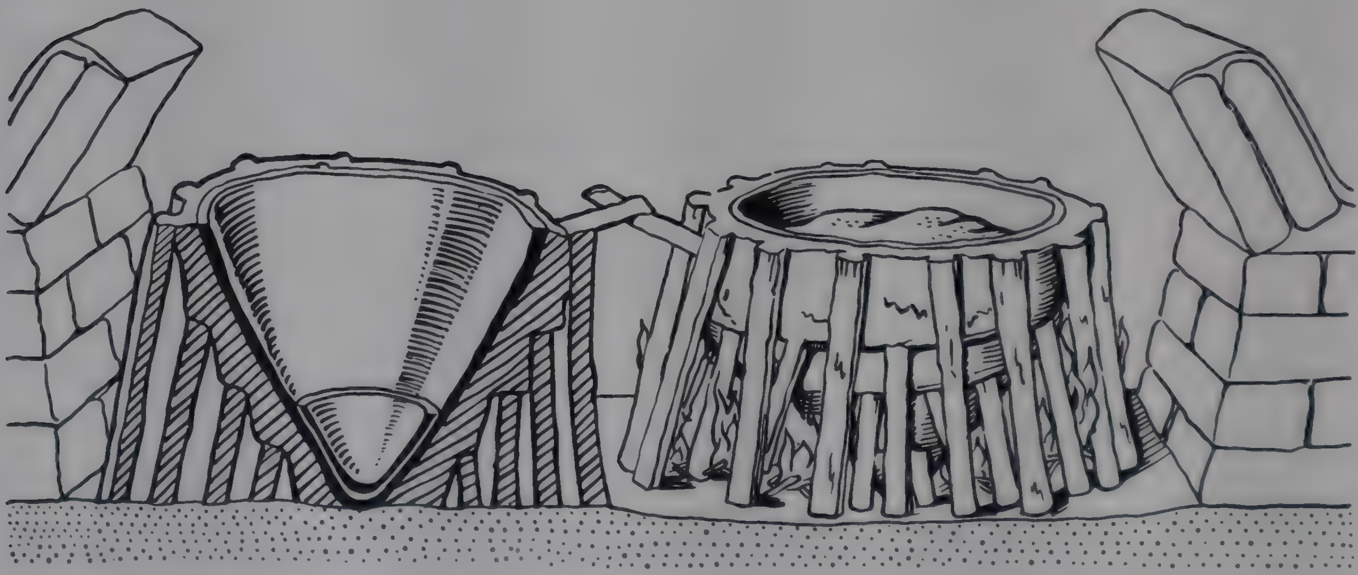


Figure 9. Two of a series of grain kilns in staggered double rows excavated near late predynastic cemeteries at Abydos, Egypt, and probably dating from the middle of the fourth millennium B.C. There were as many as thirty-five of these 3-foot-high jars in a group. The jar at the left has been cut away to show details of construction. The side wall was no doubt carried up over the jars to hold the heat, and the grain was dried, not roasted, in them. These kilns are not found after predynastic days; perhaps improvements in grinding made them unnecessary.

and food inserted for baking. To the south of Syria-Palestine in Egypt, other grain bins of equally early date have been uncovered; in the Fayum these were underground pits lined with straw matting, while later locations yield either large pits lined with thick clay walls or aboveground sun-dried receptacles whose openings were closed by stone slabs. All these village settlements also had pottery and means of planting and grinding grain; and in some of them emmer wheat and two varieties of barley have been found, with four times as much barley as wheat. Large kilns for drying grain have also been found in predynastic locations at Abydos (Figure 9).

The region to the north of the Natufians—northern Syria and the southern Mediterranean coast of Asia Minor—has been less thoroughly studied; but here early village communities are known to have existed, and grain implements have been found. Finally, very early grain-storage pits have been found to the westward on the island of Cyprus, off the Syrian coast.

This indisputable evidence of the very early practice of agriculture on all sides of the Natufian culture points to their region as the center from which it spread and indicates that it began before 7000 B.C. This is in agreement with the known facts about the ancient distribution of the wheats, facts which also indicate that all ancient wheat cultivation originally spread from a single area of diffusion, and that all varieties of wheat developed from a single parent strain.

There are three major families of wheat, and as in all other species of plant and animal life, each is marked by a distinctive number of chromosomes in its cells. These tiny units occur in a fixed number in every generating cell, and they carry the genes by which hereditary characteristics are transmitted. Here are the three groups into which botanists have divided the wheats:

> *Number 1*, the 14-chromosome group, which includes only wild and cultivated einkorn;
>
> *Number 2*, the 28-chromosome group, which includes wild and cultivated emmer as well as a number of other wheats, of which the most important, durum, is used today to produce macaroni, spaghetti, and the like;
>
> *Number 3*, the 42-chromosome group, the bread wheats, including the many varieties of the most important of all western grains, *Triticum vulgare*, or the common wheat of today; as well as club wheat, *Triticum compactum*, used in making noodles; and one or two other varieties. None of the bread wheats has ever been discovered growing wild.

In the process of fertilization one half the chromosomes are supplied by each parent. So, if we take the basic parental contribution as our scale, these could with equal correctness be called the 7-, 14-, and 21-chromosome groups. The chromosomes of numerous other grasses also occur in units of seven – barley, rye, oats, and common forage grasses of the *Aegilops* and *Agropyron* genera. These plants must all be closely related.

In all these plants chromosomes derived from one parent normally pair off with those from the other to act together, fairly uniformly, in seven-pair blocks called "genoms." The three genoms in the Number 3 group, or bread wheats, have been labelled A, B, and C (Figure 10). There is one exception: *Triticum timopheevi*, a native of Transcaucasia, has a different chromosome group in place of C, which can be called Genom D. Genom A is found in all wheats, and its source undoubtedly is wild einkorn. Genom B is found in all wheats of the second and third groups. It must have entered the wheat family by way of a Genom A wheat – almost certainly wild einkorn – in one of two ways: as a result of its having mated with a wild grass possessing Genom B; or from a forced doubling of the chromosomes of the parent wheat, accompanied by small changes in their nature, such as botanists now induce in certain plants by chemical treatment. As to Genom

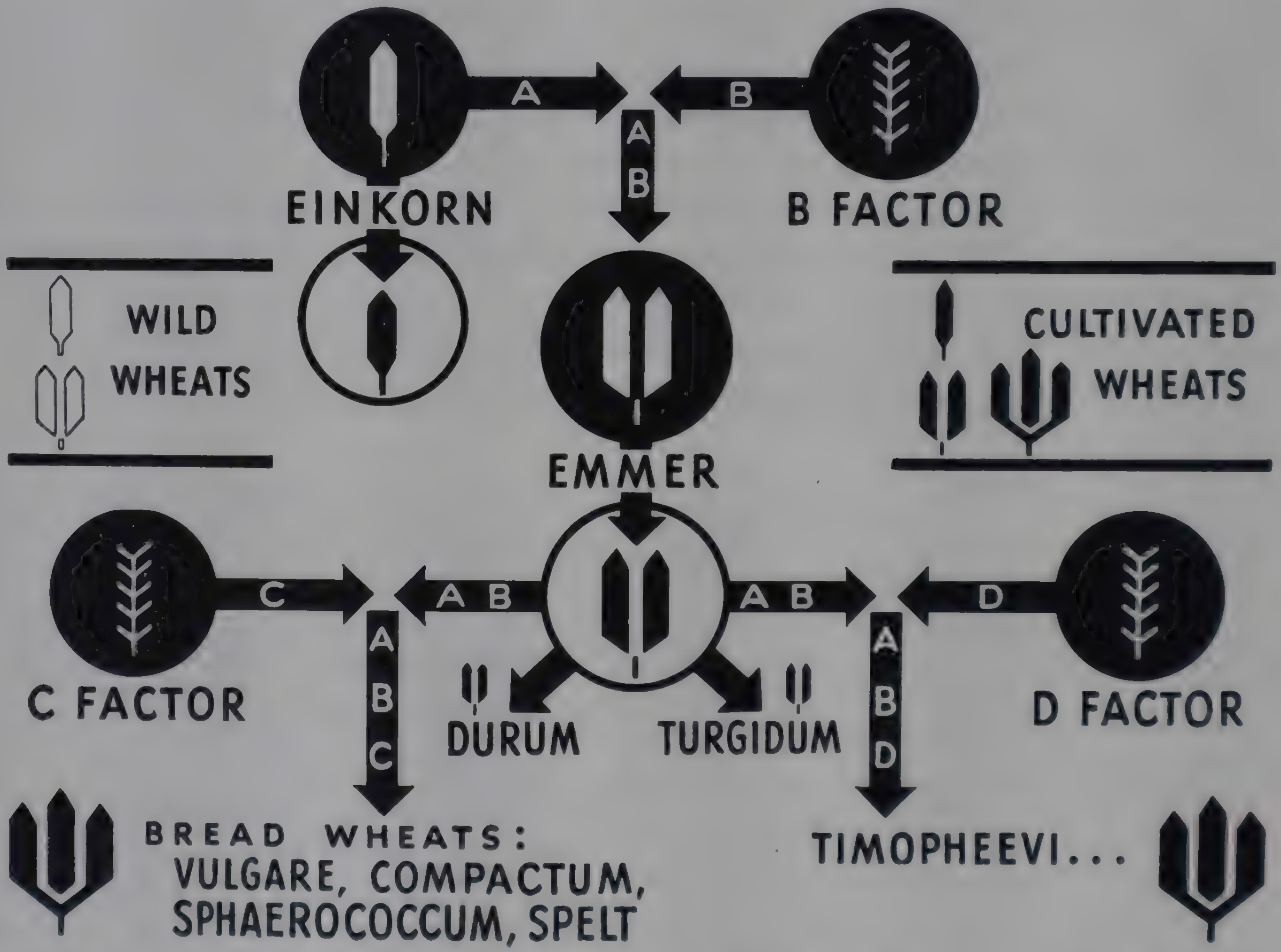

A
B
A
B
EINKORN
B FACTOR
WILD
WHEATS
CULTIVATED
WHEATS
EMMER
C
A B
A B
D
C FACTOR
A
B
C
DURUM
TURGIDUM
A
B
D
D FACTOR
BREAD WHEATS:
VULGARE, COMPACTUM,
SPHAEROCOCCUM, SPELT
TIMOPHEEVI...

Figure 10. Genealogy of the wheats discussed in the text. The letters (A, B, C, D) represent genoms – groups of seven-pair blocks of chromosomes which act as units in hereditary transmission. The A genom of all wheats is derived from wild einkorn; the B, C, and D genoms may be derived either from matings with wild grasses possessing them, or from the doubling of genoms in wheats, with consequent small changes in chromosome characteristics.

C in the bread wheats, efforts have been made to show that it came from certain species of *Aegilops* grasses. Or it too may have made its appearance by chromosome doubling. We are also in the dark as to the exact source of Genom D.

These relationships tell us that the first of the two-genom wheats must have appeared in a region where a one-genom wheat – wild einkorn or its cultivated offspring – was growing; and that the first of the three-genom wheats must have appeared in a region where a two-genom variety was already under cultivation. The einkorn need not have been cultivated, since we have a wild variety of emmer in the two-genom group, and this probably originated in a state of nature. But to get the three-genom bread wheats the two-genom parent must have been cultivated, since there are no wild wheats of this classification.

Einkorn, the parent wheat, gives a low yield by comparison with many of the later hybrids, and its grains are dark and somewhat bitter, in need of leaching; but it can grow on relatively poor soils, as in hilly regions and on arid forest-cleared lands. It was cultivated in the upper region between the Tigris and the Euphrates and on into north Syria, in the area covered by the Tell Halaf culture, and also in central Asia Minor, and possibly somewhat later (about 3000 B.C.) at Troy on the Hellespont.

Emmer is a markedly better wheat than einkorn; it requires better soil than einkorn, but it certainly would be preferred for cultivation where both grains were available and could be grown. It is found in the wild state in Syria-Palestine and elsewhere on the southern boundaries of the einkorn area, where cereal cultivation must have started with one or the other of these wheats; and it was the most widely spread of all wheats in early agricultural days. It is found along with barley in early Egyptian settings, where it was the only wheat grown in early times, and it was a staple grain in Mesopotamia. In Europe, it was grown extensively on the wind-deposited loess soils of the Danube Valley, which were easier to work with primitive tools than the cleared lands.

With the advent of three-genom, or bread, wheats, two new and powerful influences affected the spread of wheat varieties and the progress of the milling art. In the first place, hulls that are difficult to remove surround the bran-coated kernels of both emmer and einkorn. Though this is not true of durum and *turgidum* (both of the two-genom group), durum is not easy to mill on account of its hardness, and *turgidum* is among the poorest of the wheats, although it gives good yields. The bread wheats have naked kernels – all except spelt, which dates only from Roman times, when it first appeared in south-central Europe. Other things being equal, the naked wheats, and especially the naked bread wheats, are much to be preferred to wheat with hulls, as likewise to barley, on the grounds of both easier milling and better taste.

Secondly, the difference in hardness of the starchy wheat kernels became an important influence in the selection of wheats. This variation is wide – from the sometimes even flinty durum (the name means hard) to the almost chalky club wheat (*Triticum compactum*), a member of the bread group. Einkorn and emmer are hard wheats when compared to the bread wheats, but they are not so hard as durum. The bread wheats differ among themselves in this respect, and in particular common wheat as grown today can have almost any degree of hardness.

With primitive milling implements, and, in fact, throughout the entire history of milling until rollers came into use in the late nineteenth century, the softer wheats were preferred – in early days because they were easier to grind, and after sifting became important, because the bran could be separated more easily from the starchy endosperm. At the same time, as methods of sifting became more efficient, durum, a hard but naked wheat, gained somewhat in favor. It was increasingly consumed in Roman days, as against emmer, because emmer has hulls and because the Romans became expert in sifting.

All evidence indicates that Iran, to the northeast of lower Mesopotamia, was the center in which the three-genom bread wheats originated. Emmer, the undoubted wheat parent of three-genom wheats, has been found there at a number of old sites, and while actual examples of the bread wheats are yet to be found in Iran, they have been discovered in the surrounding regions, indicating that they spread from there as a center. *Compactum* probably originated in Iran in the fourth millennium B.C., *vulgare* either to the east of Iran, in Afghanistan, or to the north in Russian Turkestan or Transcaucasia, say in the third millennium B.C. *Sphaerococcum* is primarily an Indian wheat. From Anau the bread wheats spread to China; from South Russia they spread to western Europe, where they are found at later dates than emmer, and consequently than einkorn.

All this evidence adds up to a conviction, shown diagrammatically in Figure 11, that grain cultivation began either in Syria-Palestine with einkorn or emmer, or started a little farther to the north along the southern foothills of the Anatolia massif with einkorn, and was rapidly transferred to emmer in the Syria-Palestine region; that emmer spread thence in two directions – by way of Palestine to Egypt, and by way of northern Mesopotamia (along with einkorn in highland regions) to Iran, where the bread wheats were somehow hybridized; and that the bread wheats spread from Iran in all directions – to southern Mesopotamia, to India, to Russian Turkestan (and from there to China), and to South Russia.

Europe first received its wheat in the form of einkorn by way of Troy, starting about 3000 B.C. or a little earlier. Einkorn traveled up the Danube Valley and on to western Europe, where the Rhine was reached about 2700 B.C. and Denmark a little later. Emmer was first carried into western

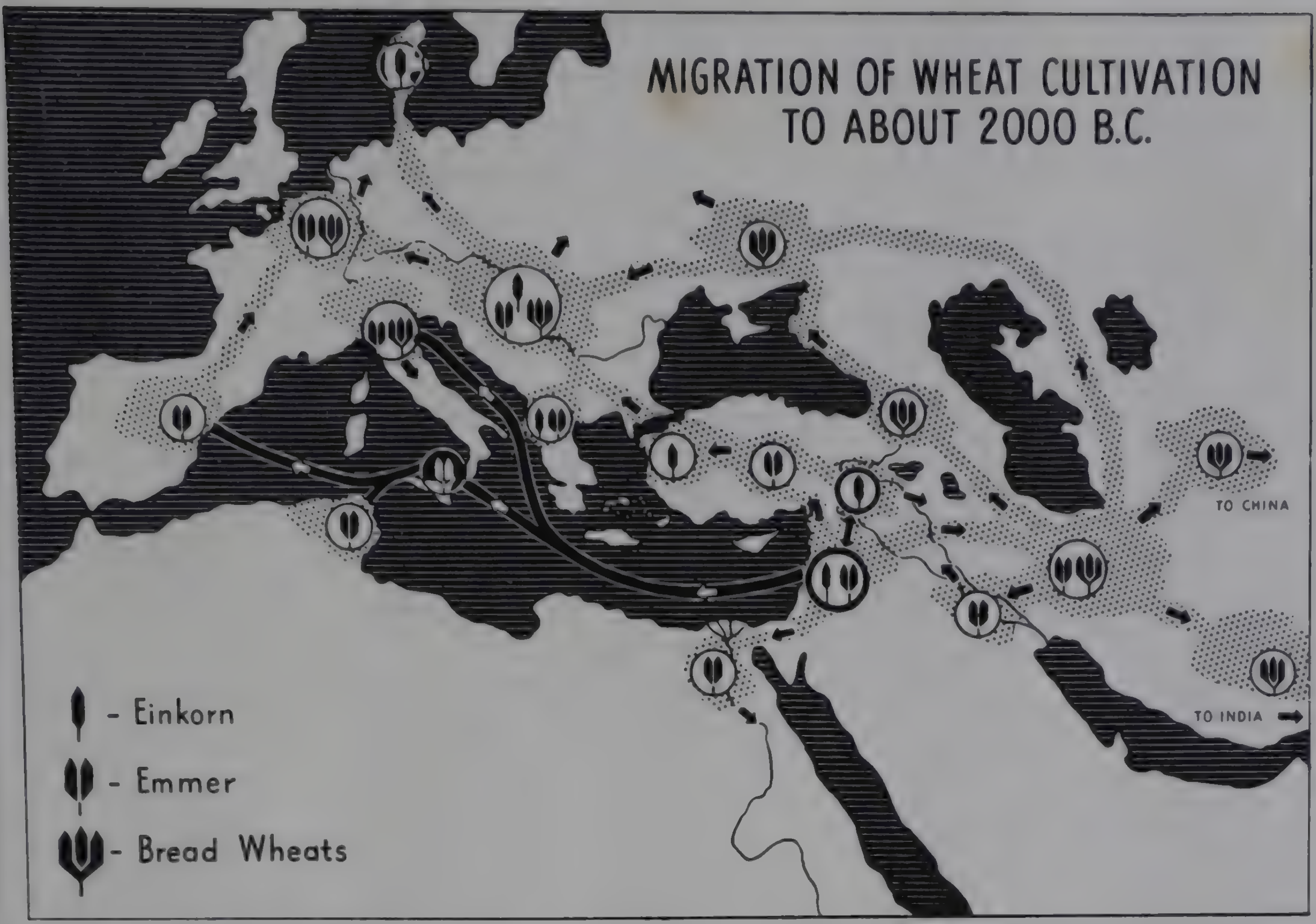


Figure 11. Diagrammatic chart of the spread of the wheats from Syria-Palestine, the place of first cultivation about 7000 B.C. (indicated by the two heavier circles), throughout the Near East and Europe, up to about 2000 B.C. Only the more important paths followed by wheat cultivation in its spread are indicated. Note the central position of Iran in the spread of the bread wheats, and also the part played by the central Danube Valley as a secondary center of diffusion.

Europe by way of the Mediterranean to Italy and Spain, largely by traders in search of copper and tin. It traveled up the coast to reach Denmark by about 2300 B.C. The bread wheats—that is, *compactum* and *vulgare*, the master wheat of modern times—spread over Europe from South Russia beginning about 2100 B.C.

The bread wheats came into western Europe as improvements on existing wheats, not as initiators of agriculture there. It is quite possible, though the point is obscure, that their spread depended on an improved plow, since they require deeper tillage and are more dependent on animal manure. They are artificial wheats, totally incapable of maintaining themselves without human effort, but able to grow in climates very different from that natural to the wild wheats. Early wheats of all varieties required a dryish, rather warm climate and grew in not very good soils—that is, until their appearance in the Nile and Tigris-Euphrates valleys. Today the best wheats grow in rich soils in regions with long, cold winters and considerable rainfall, where a warm, dry harvest period favors ripening of the grain and improves its protein content.

Under the attention given them since the beginning of agriculture, the wheats have shown an amazing variability. John Percival, whose book *The Wheat Plant* is authoritative, has described about two thousand variant wheat forms, of which *vulgare* accounts for over 65 per cent. Without *vulgare*, which can grow if the average temperature is no lower than 57°–58° for the three warmest months, civilization could not have continued that march away from the equator which characterized it up to the discovery of America.

Europeans carried wheat, almost invariably *vulgare*, with them to all temperate parts of the globe during the great expansion movement which began in the sixteenth century. It was only in the late nineteenth century that durum, the macaroni wheat, was introduced into the United States from South Russia. *Compactum* is the only wheat other than *vulgare* and durum now grown extensively in this country.

When the white man first reached the Americas, he found the Indians already cultivating scores of plants unknown anywhere outside the Western Hemisphere—beans, the sweet and white potato (the latter in South America only), the squash, pumpkin, tomato, pepper, peanut, pineapple, and many another edible plant. But the most important of all was Indian corn, or maize, whose cultivation had spread everywhere on the two continents throughout its climatic range. Clearly the human race independently invented agriculture at least twice in the course of its history.

Teosinte, often considered the ancestor of corn, is a wild grass native to Mexico and Central America; but it is much further removed from the cultivated grain than is einkorn or emmer from the bread wheats. Corn has been so thoroughly domesticated that it can no longer seed itself; for continuous growth from season to season it is completely dependent on man. It is now a thoroughly civilized grain, parasitic on human civilization.

We do not know within five thousand years when agriculture was first practiced in the New World. It is very likely that the earlier Mayans were the first New-World cultivators: tradition credits them with the achievement. By the beginning of the Christian era, as the Pueblo culture emerged, corn agriculture completely overshadowed all other means of food getting in our Southwest. Farther north, some at least of the prehistoric Mound Builders combined agriculture with hunting. By the seventeenth century agriculture was thoroughly established over the whole eastern part of the United States—so much so that Denonville, a Frenchman, in 1687 claims to have destroyed 1,200,000 bushels of Seneca corn, standing and in store, in the Genesee Valley near the present city of Rochester, New York. The grain penetrated neither the Great Plains nor California.

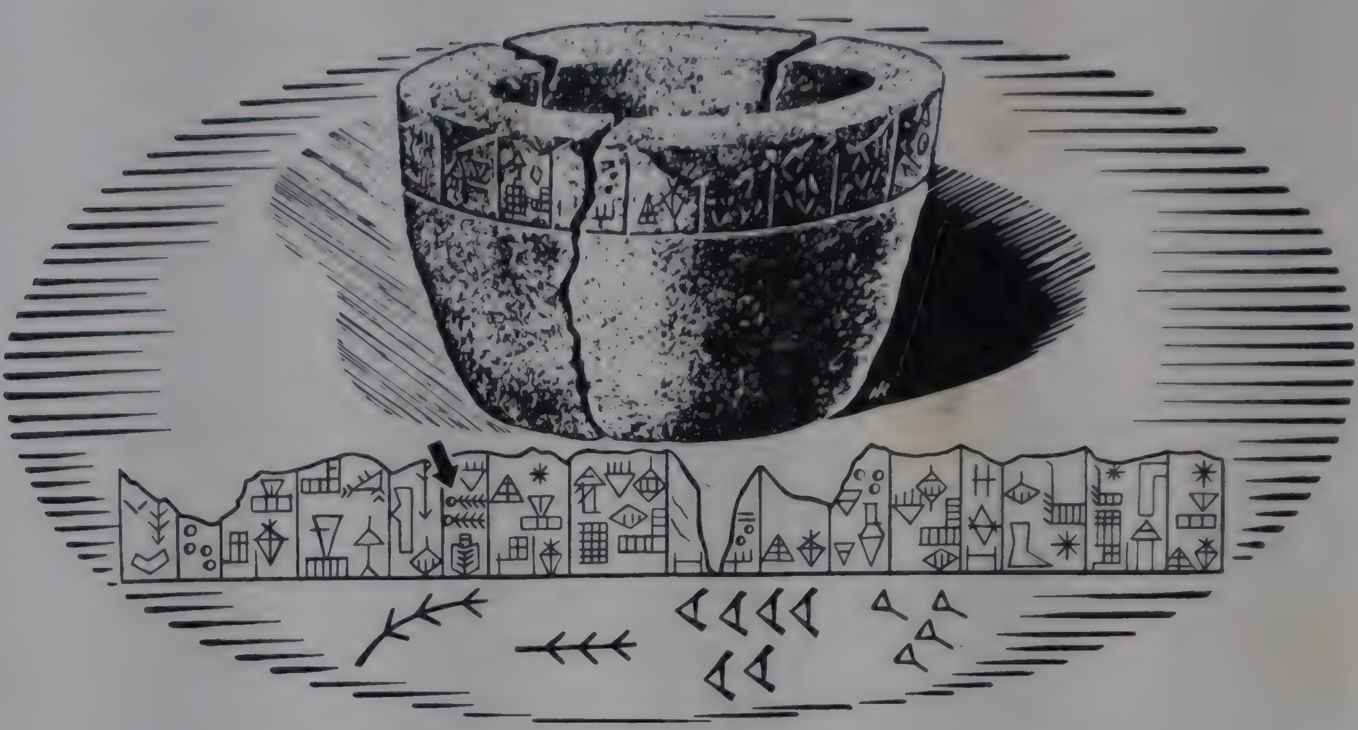
In North America, wheat is cultivated in latitudes well to the south of the European regions whence it came, owing to three circumstances. In the first place, these latitudes are much cooler here than the same latitudes in

Europe, since the latter are warmed by the prevailing west winds blowing over the Gulf Stream. Secondly, new types of wheat have been developed in the United States, largely on the *vulgare* stem, adapted to conditions in Kansas and Missouri and regions even farther south than our great corn belt.

A word should be added about two other human food grains requiring grinding—barley and rye. Barley grows wild in the Syria-Palestine area, and may easily have been cultivated as early as wheat; the two "are twins of one home and age." It too exists in 14-, 28-, and 42-chromosome forms. It would hardly be possible to prefer barley as a food staple to any of the wheats, but it produces more per acre and will grow on poorer lands than wheat. Since it is a cheaper grain, it was eaten very freely in early days by the poorer classes of people, and was for long a basic grain in Mesopotamia and in Egypt. The rise of 42-chromosome wheats in the ancient classical world spelled the doom of barley as a human food staple, since they permitted the making of genuine bread—a leavened and aerated loaf. Given time, wheat bread was bound to win favor over all other basic Western foods because of its cheapness no less than because of its superior quality.

The only other grain from which genuine bread can be made is rye, which is hardier than wheat and more adapted to worn-out soils, giving better yields under unfavorable conditions. We have no record of this grain before the Christian era. In northern Europe it was the principal food staple from the medieval period until the late eighteenth century in England and even until the nineteenth century on the Continent. Although the world as a whole consumes much less rye than wheat, rye is today the staple bread grain of a large part of north-central Europe; in past years, before World War II, Russia and Germany between them grew over 70 per cent of the world's crop.

The treatment of the various cereal grains differs in detail, but fundamentally they all are grown and ground by the same methods and tools. In discussing the early techniques of cultivation and milling, it will not be practicable to distinguish the grains that were treated by the various methods described. But the basic techniques were all worked out in the great wheat-growing regions of the Near East and Egypt, whence they spread throughout the agricultural sections of the ancient world. In new countries they were subject to some local variations, especially in tools, and specific adaptations to different grains were worked out. But throughout the whole history of agriculture, wheat-growing led the way in agricultural progress, and wheat-processing led in the progress of milling: whatever new techniques were developed for the master grain were available for adaptation to the others.



CHAPTER V

Farming and Milling Tools Appear—and Bread

> Before agriculture, the earth could have supplied no more than 20,000,000 people. Now the world's population is 2,000,000,000.
>
> –D. C. Wing

THE period in which agriculture had its beginnings is known, with erroneous emphasis, as the Neolithic or New Stone Age. Since its very fine and shapely polished stone tools are its principal surviving relics, it was natural that they should give the period its archeological name. But the really momentous thing that was happening at that time was not a new way of working stone but a new preoccupation with working and planting the soil and processing the grains. From this labor was to come whole new classes of tools, arts, and living habits.

The first phase of wild-grain tending was to clear away encroaching growths, to give the grasses room to spread. For this the common hand axes of stone were adequate. Later, when purposeful reseeding of the

Chapter head oval. Mortar of Enannatum I of Lagash (2750 B.C.). An arrow on the protocuneiform inscription marks the symbol ŠE, which signifies *wheat*. Below, stages in the development of this character into its later cuneiform representation.

grasses was undertaken, it was found that results were better if the ground was opened and the seeds placed safely within it. For this the most primitive of all agricultural implements – the digging stick to punch a hole in the ground – was the first recourse. In time it was observed that the grain grew faster and more sturdily in loose ground than in hard, and hand axes again were used to break up the soil; here was the beginning of tillage.

Someone realized that the tilling implement would do a better job if its blade was placed broadside to the handle, and this man invented the hoe. Stages in its early development can be traced in Figure 12. From these types it was only a step to the Egyptian back-handled hoe of Figure 13.

Hoe culture was carried on by women, who may be given chief credit for many of the race's early achievements; and, except in special circumstances, it was carried on by nomadic peoples who were forced to move frequently in search of new fields. The full fruitfulness of settled agriculture was realizable only after a larger and better kit of farming implements

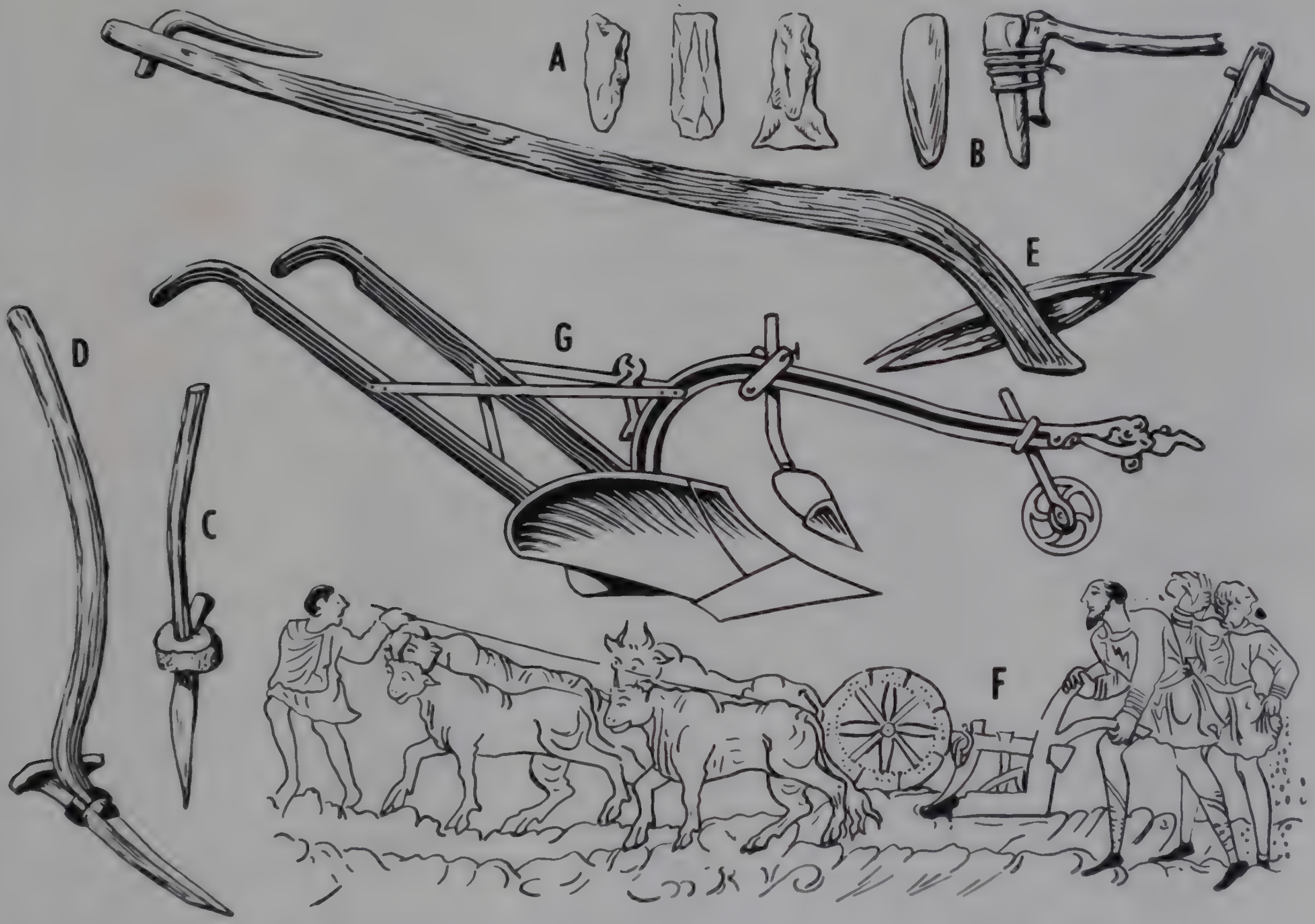


Figure 12. Methods of opening the soil for planting. A, stone hoes from Kish, Mesopotamia, dating from about 3000 B.C. B, shoe-last celt from the Danube Valley (about 2000 B.C.), also manner of hafting stone hoes and celts. C, digging stick with weighted stone for foothold, still used by Negroes in central Africa. D, *caschrom* or *arad arsang*, still in use in remote islands off the Scotch coast. E, *ard* plow found in Denmark, from the pre-Roman Iron Age (possibly 300 B.C.). F, English plow, from Cottonian MSS (eleventh century A.D.). G, a modern walking plow.

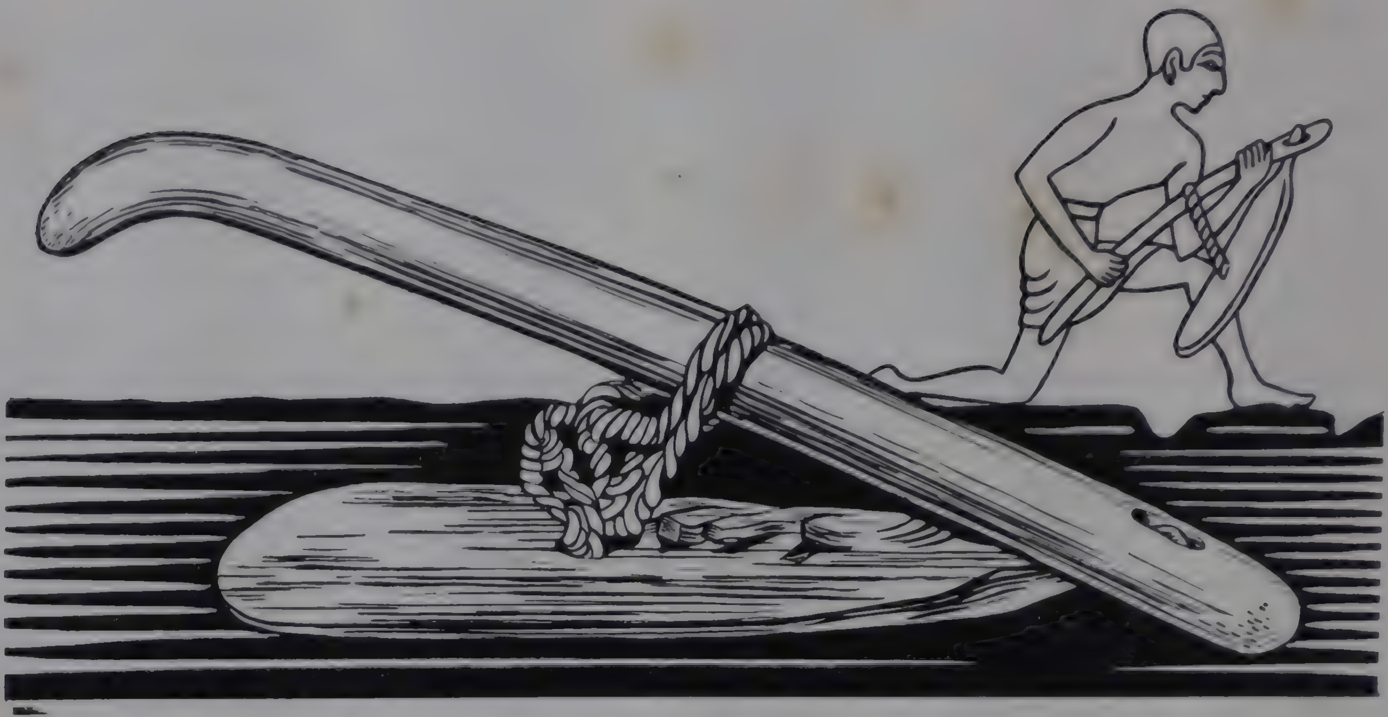


Figure 13. Egyptian back-handled hoe, found intact, from the first millennium B.C. This implement appears on early tomb paintings, back at least to 3000 B.C., and was a step toward the invention of the plow.

had been devised and used in regions where nature replenished the soil, or after farmers themselves realized the importance of refertilization. Even the rich soil of the Danube Valley could stand only a few seasons of unfertilized planting.

With a hoe the broken ground is pulled toward the user. Another basic action in tillage is possible: a similar broad-bladed implement, with the blade placed as an extension of the handle, can be thrust into the soil, which is then lifted forward and turned over. Out of a weighted digging stick developed the spade, and with it deeper and more thorough tillage was possible. The spade ultimately suggested the plow, not to be pushed but *pulled* forward by men or animals.

For many obvious reasons the plow was a much more difficult implement, both to invent and to use, than any hand tool. The first light plow, or *ard* (cf. the Latin *aratrum*), of which we have knowledge is shown on an archaic Mesopotamian seal from the royal cemetery at Ur, dating from about 3500 B.C. The implement must have come into use considerably earlier, since its form is already established—seal depictions over a thousand or more years differ only in details (Figure 14). From about the middle of the second millennium B.C., Mesopotamian plows are shown with seeding tubes (Figure 15), thus anticipating the modern corn drill.

The difficult *ard* suggested the use of powerful, slow-moving, phlegmatic oxen to drag it, and this in turn meant that the strength of men was needed to guide beast and plow: agriculture became a masculine art, and fields became larger and more orderly than under hoe or spade tillage. The heavy plow (reputedly from the Rhaetian root *plaum*), with wheeled

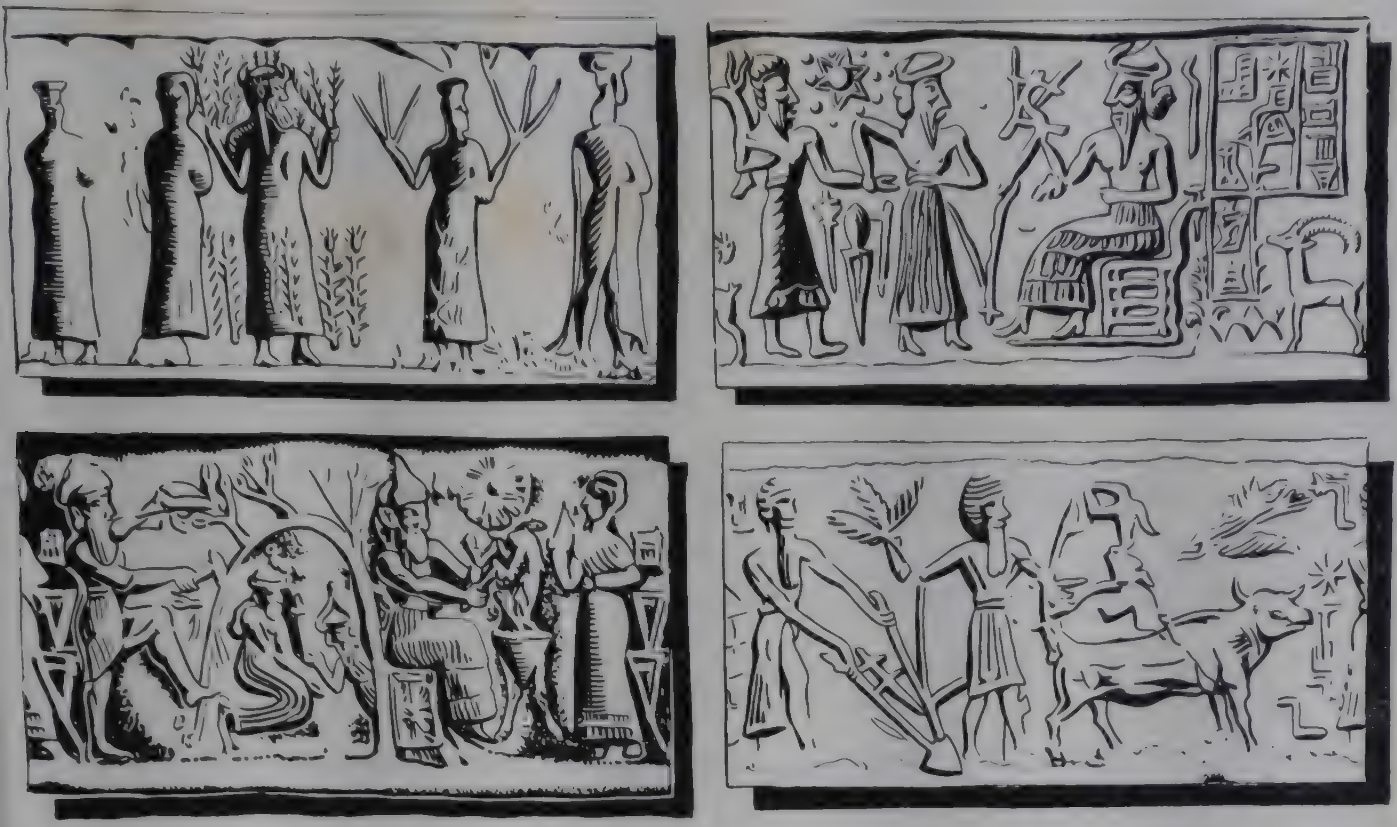


Figure 14. Assyrian cylinder seals from the time of Sargon (722–705 B.C.). Upper left, the god Tammuz producing grain around him and from his robe and body. Upper right, a god holding a plow of the familiar Mesopotamian type. Lower left, the mother goddess has just found Tammuz "in the mountain," symbolically indicated by a bent-over tree, which is being hacked at by Nergal, the sun god – a force inimical to life in Mesopotamia, with its almost unendurable summers. Lower right, ox-drawn plow with seeding tube.

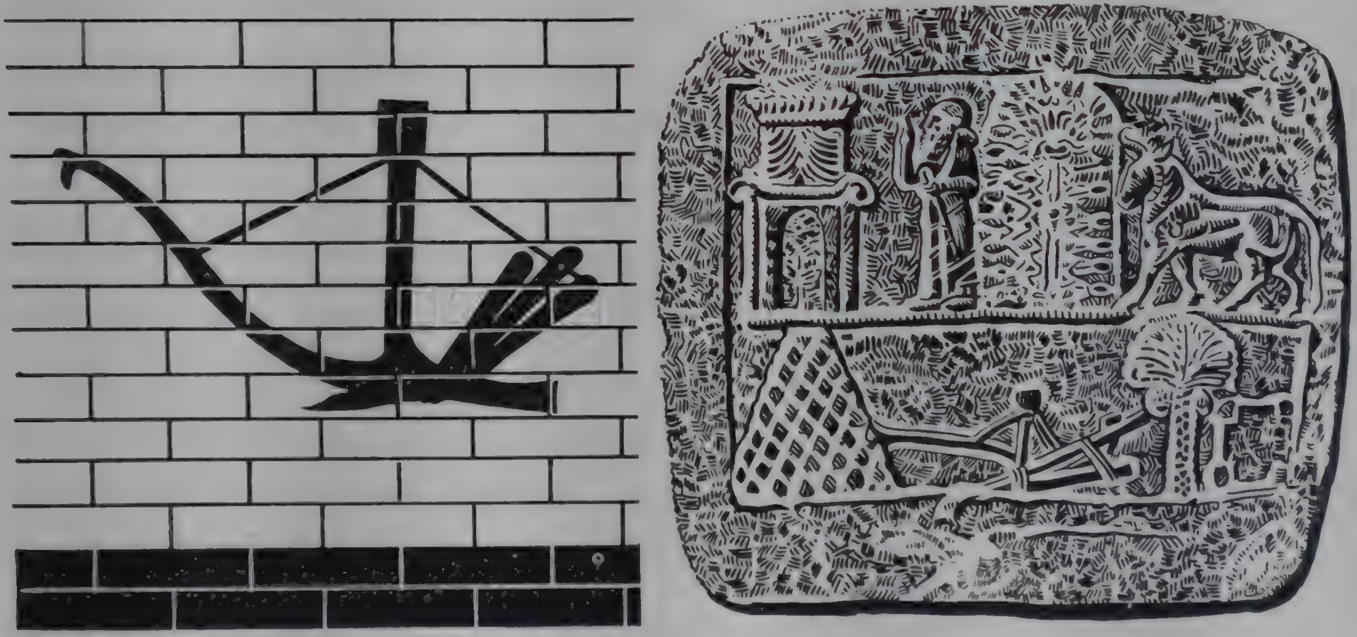


Figure 15. Assyrian plows. At the left, a tile wall in the palace of Sargon (722–705 B.C.). At the right, a metal relief from the time of Esarhaddon (681–668 B.C.). These plows had seeding tubes.

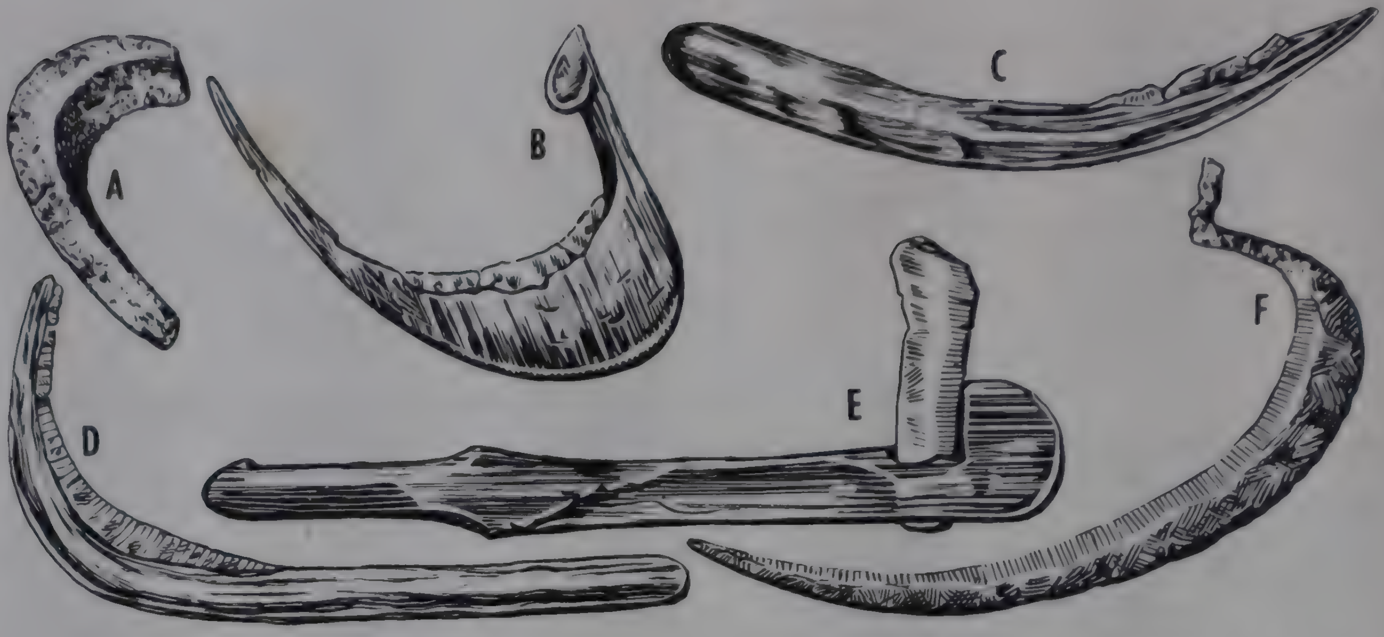


Figure 16. Sickles. A, a pottery sickle from Jemdet Nasr (well before 3500 B.C.), of a kind found in great numbers at many early southern Mesopotamian sites, where stone and wood were scarce. B, a Twelfth-Dynasty Egyptian wooden sickle handle found with flints inlaid, from about 2000 B.C. C, a horn-handled sickle with inlaid flints from Karanovo, Bulgaria (about 2000 B.C.). D and E, single-blade flint sickles with wooden hafts from Denmark, the latter the famous Stenild sickle, found complete with its handle (1000 B.C.?). F, for comparison, a medieval balanced iron sickle. This last instrument will not turn in the hand when being used, as would the others.

forecarriage, colter to cut the soil, and moldboard to turn it (Figure 12), did not appear in Italy until the second or third century B.C., coming from central or northern Europe, where it may have been invented to handle the heavier soils of the region. Even with the light *ard*, agriculture was ready to become a settled and serious occupation, the life work of men who kept domestic cattle and so could refertilize their fields. With the heavy plow, it could be carried into any part of the world where soil and climate were favorable to annual crops.

New and better reaping implements were devised (Figure 16), along with tillage tools, but all were inefficient. With a sickle of the Stenild type, Curwen cut and laid out neatly 15 square yards of wheat in an hour: it would have taken him about 160 hours to mow an average primitive half-acre plot. It was not until the Iron Age that balanced sickles were made. In the same period scythes were invented – long-handled implements for mowing in broad swaths from an upright posture, instead of in the short strokes from a stooping position that sickles enforce. A scythe again is a masculine implement, while women or even children can wield a sickle. Sickles remained in favor for this reason, and also because with them a clutch of ripe grain could be cut off near the top, leaving the straw to be cut later. By this method the valuable straw was saved from the destructive beating – "threshing" – which the heads of grain must receive.

To be threshed, the heads were spread on a cleared plot of hard ground, and animals were driven round and round on them. In Roman days, and perhaps before, the *tribulum*, composed of a multitude of microlithic flints set in a board and weighted down with stones and the driver, was dragged over the grain (Figure 17). In medieval times, and in America until the advent of the threshing machine, grain was beaten out with flails, on hard ground or a "threshing floor." Winnowing was accomplished by tossing the grain into the air, the lighter chaff being blown away.

As the supply of grain increased under cultivation, grinding tools improved to keep pace with the better tools of agriculture, and the advantage of adapting the grinders to specific motions became apparent (Figure 18). For up-and-down pounding the mortar form obviously was best; in some places these mortars developed into tall cylinders, but more shallow forms, adapted to a circular motion with some pounding, were usually preferred because of the difficulty of shaping the stone inside and out (Figure 19). For back-and-forth motion, the most important of early milling tools was devised, the saddlestone or metate. This implement in its most primitive forms requires far less shaping than do mortars, and allows more precise control of the grinding.

The pounding of grain in mortars was an obvious though crude means of reducing it to meal, and this method of milling was practiced for a long time by many peoples. In the beginning, mortars were crude affairs, and some were even unfitted to be stood upright during use. These were probably held between the knees or embedded in the ground. For a pestle, almost any long, narrow stone could be made to serve. Figure 19 shows a

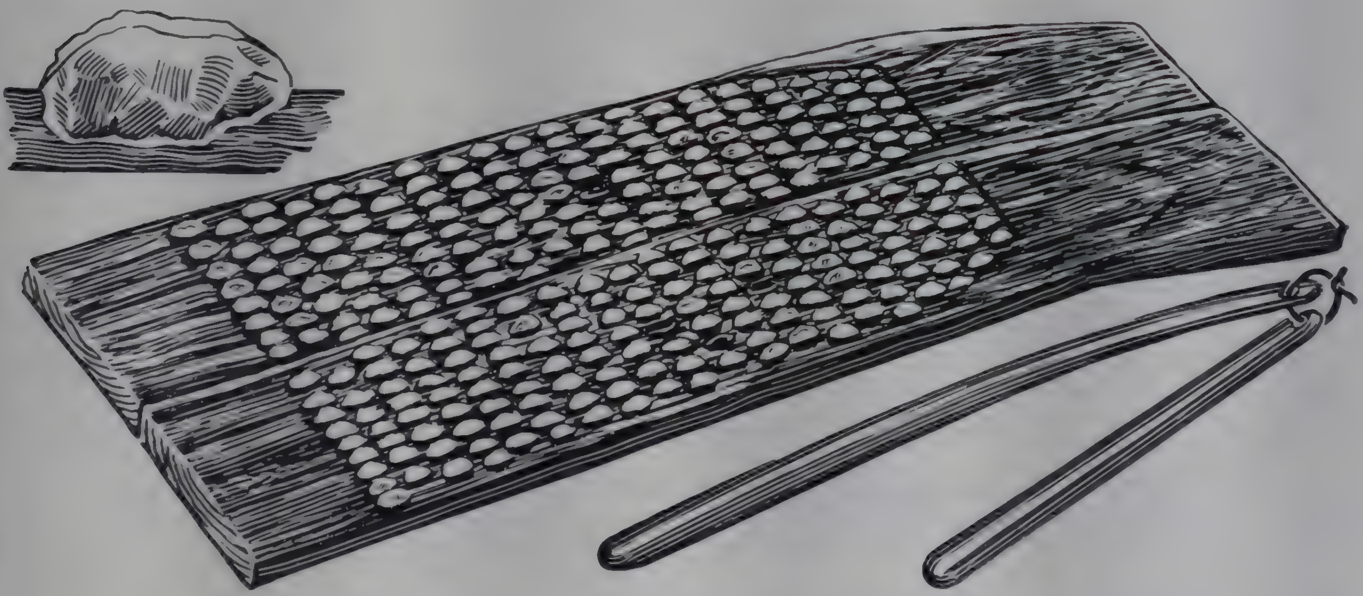


Figure 17. In the center, a modern *tribulum* from Cyprus, similar to those used in early times, with its under side up to show the rows of small flints set in the surface after the manner of the one at the upper left (approximately half size). The *tribulum* was weighted and dragged over the spread-out stalks of grain to thresh out the kernels. At the right, a flail; the operator grasps the longer stick near its end and beats the stalks to release the kernels.

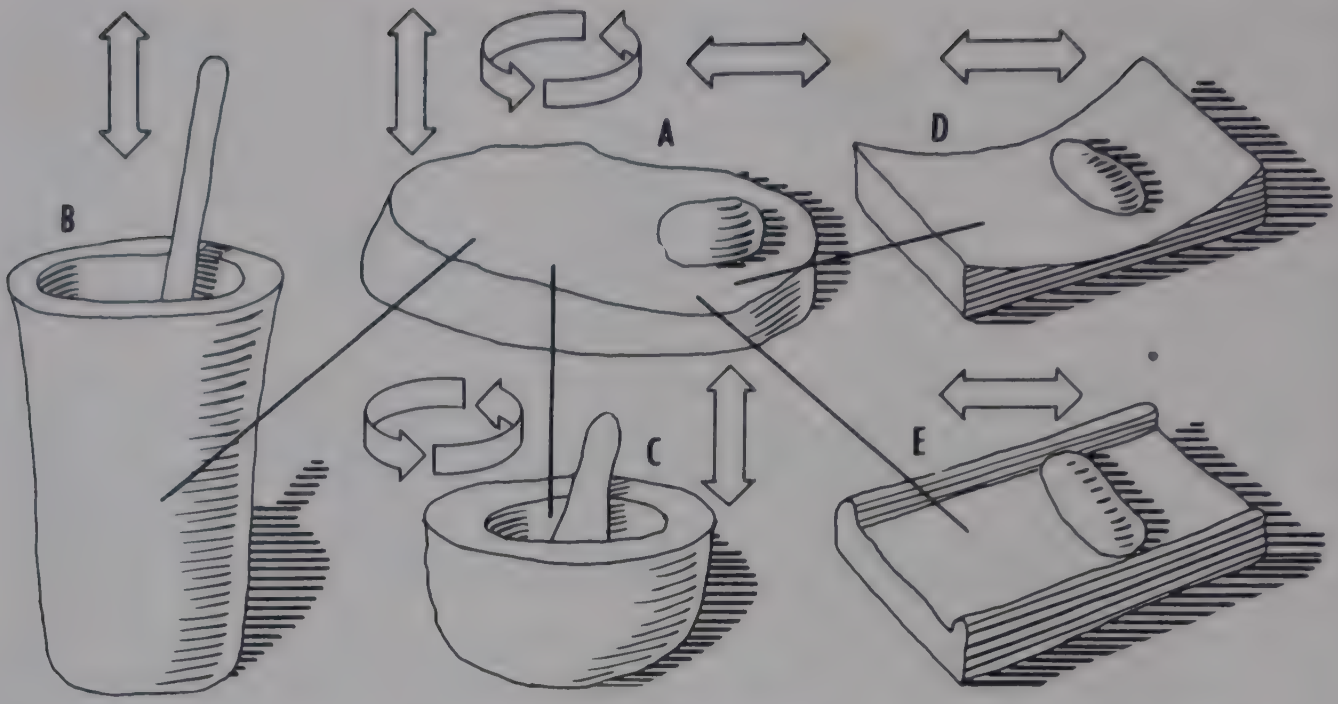


Figure 18. Motions used with early milling implements. A, pounder-rubber: indiscriminate motions. B, tall mortar: up-and-down motion. C, shallow mortar: round-about motion, with some pounding. D and E, saddlestone-metate form: back-and-forth motion. Two ways of channeling the last motion — by curving the lower stone and by providing side ridges — are shown.

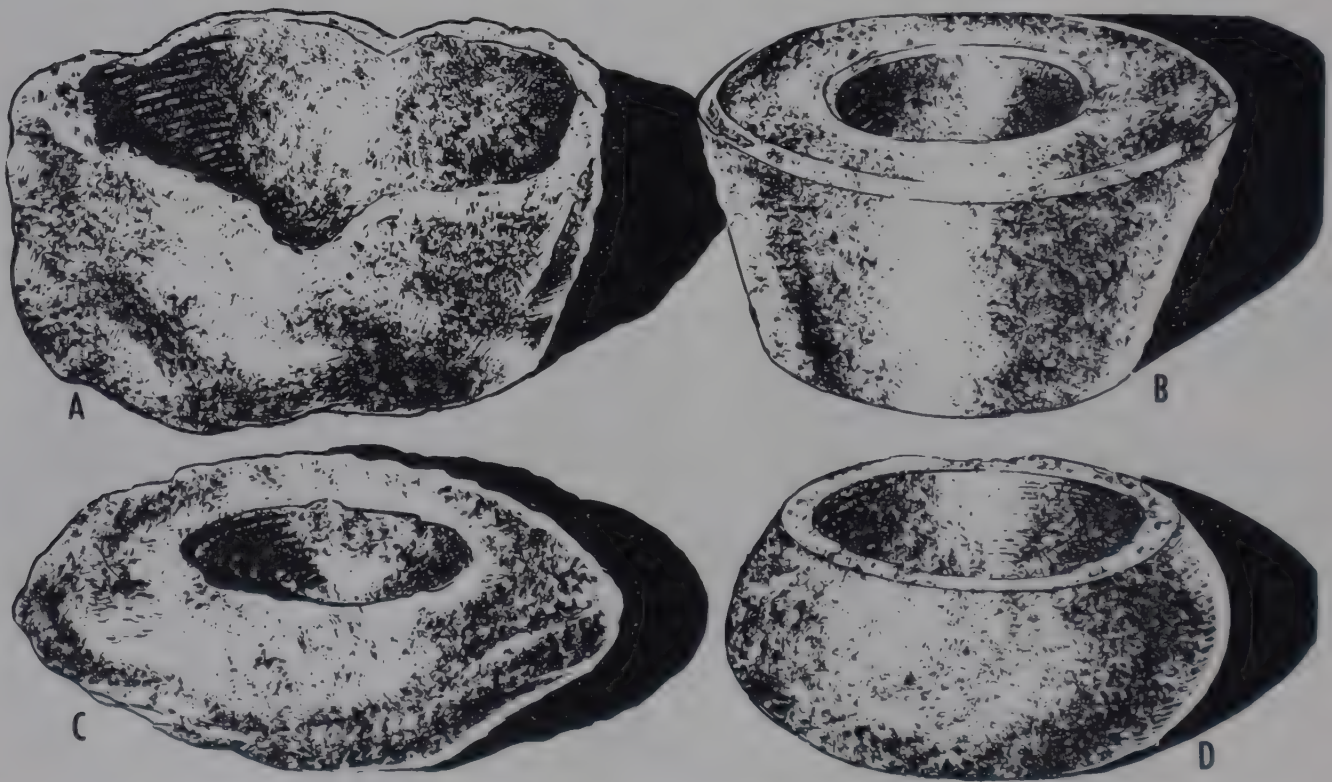


Figure 19. Crude and skillfully shaped mortars from the Old World and the New. A, from Neolithic Olynthus in northern Greece (about 3000 B.C.). B, from Kish, Mesopotamia (about 3500 B.C.). C, from the Chiricahua stage of the Cochise culture of Arizona (before 3000 B.C.). D, from the Hunting People stage of the Santa Barbara region of California (date unspecified, but before A.D. 1000).

number of mortars in various stages of development, and behind them must stand a procession of more primitive forms, as yet unfound.

A superb example has come down to us from the third millennium B.C., identified by a protocuneiform inscription encircling its rim as the property of Enannatum I of Lagash in Mesopotamia (Oval, Chapter V). The inscription hails Ningirsu, god of agriculture and patron deity of Lagash, the warrior of En-lil, chief of the gods, and dedicates the "mortar for grinding wheat [ŠE – marked by an arrow in the figure] for the prolongation of the life of Enannatum, *Patesi* [ruler under the gods] of Lagash." The still pictographic character of the grain symbol is evident.

The mortars of Figure 20 show how good sense in the face of a substantially identical problem can lead to very similar solutions in places widely separated in space and time. If one were to set out to make a mortar from a tree trunk, this is the only form it could take. But the pestles are another matter; their common shape is due to a similar awareness of efficient conditions of use. With heavy pestles like these, a man's strength may be needed to wield them; also they can be used by two persons pounding in rhythm. This ability to accommodate two workers at a time, which the

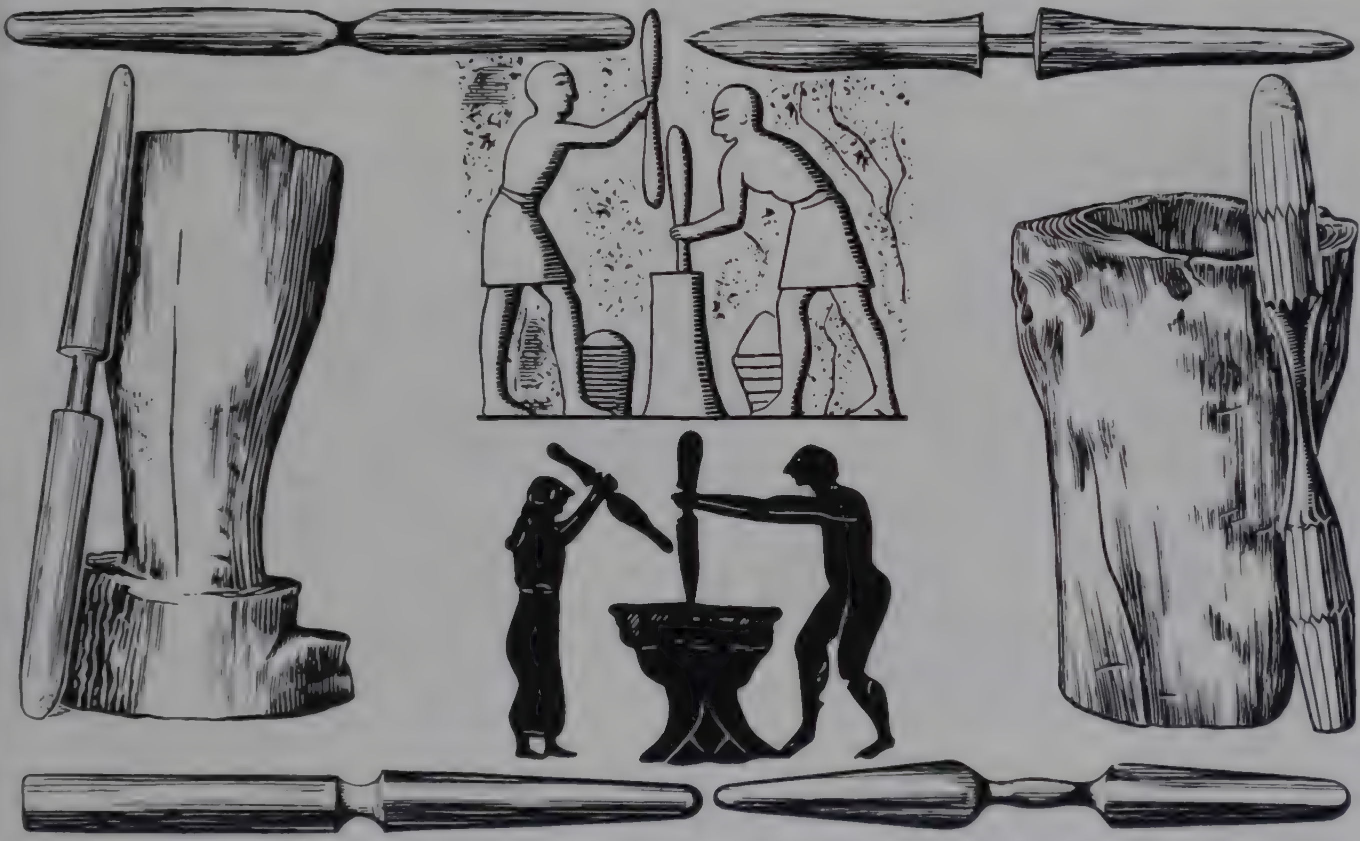


Figure 20. Tall mortars. At the left, a tree-trunk mortar and pestle from the Swiss Lake Dwellers (about 1500 B.C.). At the right, similar forms from nineteenth-century Iroquois Indians of upstate New York. Above, two men pounding together in a mortar, from an Egyptian tomb painting of about 1450 B.C. Below, a man and woman pounding together, from a Greek vase painting of about 500 B.C. The pestles framing the illustration at the top and bottom are from Greek vases.

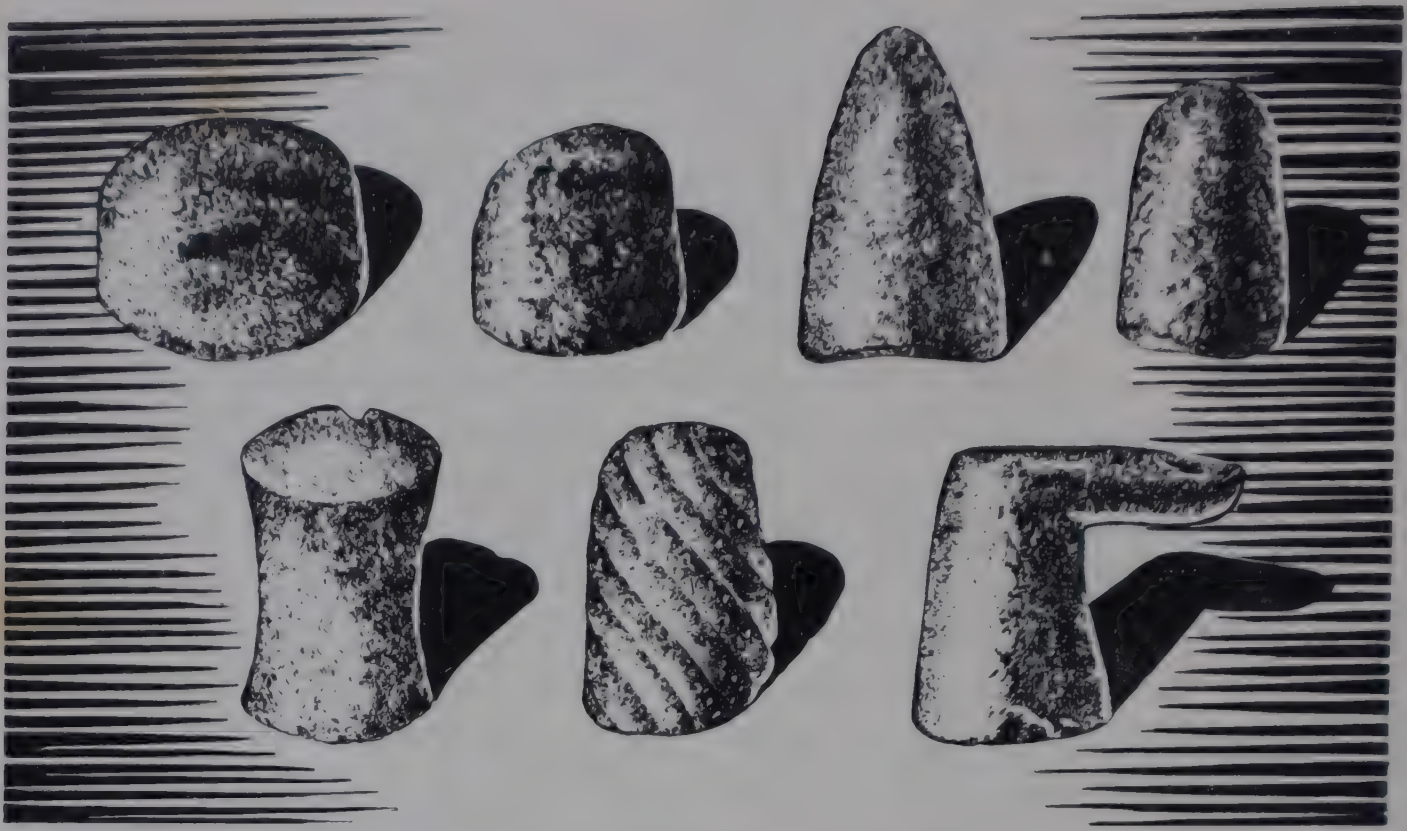


Figure 21. Pestles for holding between the fingers to pound substances, including grains, in shallow mortars. Though the shapes differ, the function performed is the same. From the Aegean Island of Delos; all are pre-Greek except the two at the right in the lower row.

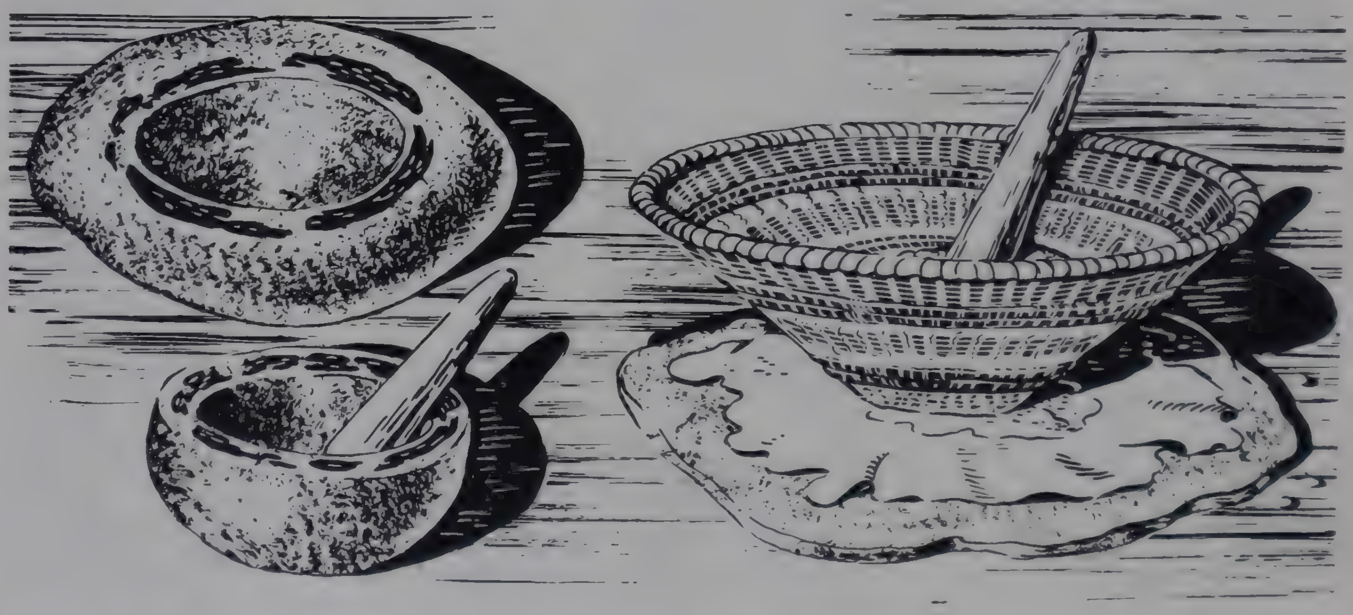


Figure 22. Basket mortars. The examples at the left are from the Santa Barbara, California, Indians: the upper flat one from Rogers' Hunting Period (before A.D. 1000), the rounded-out form from his later Canalino Period, which is also pre-Spanish. The baskets, now missing, were attached to the stones with pitch. At the right, a modern Hupa basket mortar, in which the basket was simply set on a flat stone covered by a buckskin or piece of cloth.

saddlestone cannot do, may be one reason for the long survival of this relatively inefficient type of mill. Shorter pestles could vary widely in shape, as will be seen in the collection shown in Figure 21.

Community mortars, consisting of a number of hollows in a large bed rock, are found in numerous Amer-Indian locations, and more sparingly in Old-World sites. These would allow the wives to gossip at their work, as French women today gather at a single spot on the river bank to do their family wash. Some Amer-Indian tribes made mortars whose base was a flattish or somewhat rounded stone, which was used in conjunction with a side wall of basketry, attached to the base by asphalt (Figure 22). Such mortars occur chiefly in California and adjoining regions; they do not permit as strenuous pounding as all-stone forms.

The simple up-and-down motion of the pestle suggested various ways of assisting the operator (Figure 23). The Lazy Jim, which frees the operator entirely by substituting running water for human muscle power, has been widely used from the Orient to our own southern mountains. The Japanese have Lazy Jims with water boxes on shafts pinned to the beam by a crank, and rotating as a crude water wheel. As late as the eighteenth century, true water wheels or animals were used to drive a kind of stamp

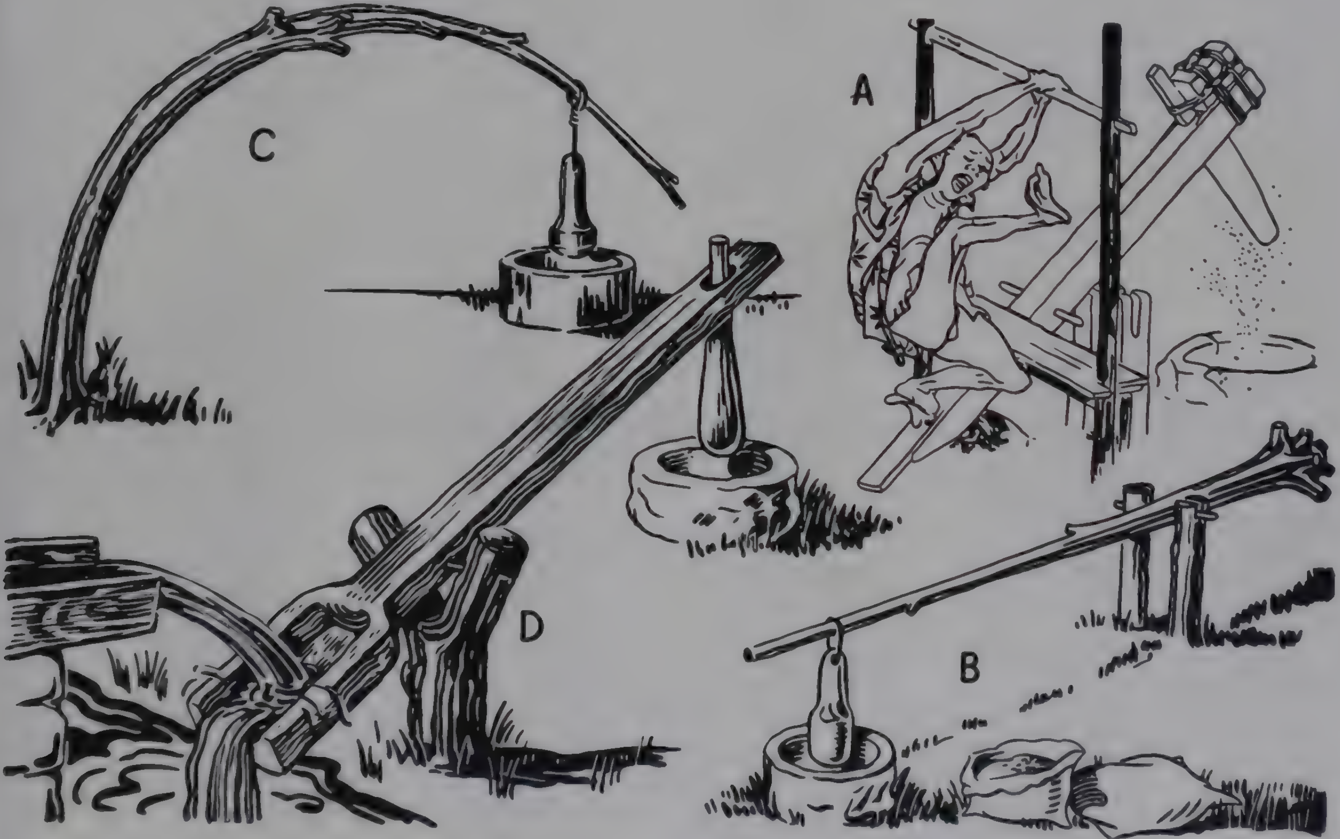


Figure 23. Ways of supplementing arm power while using mortars. A, foot-driven pestle, from an early nineteenth-century print by Hokusai. B, the root of a tree trunk used as a counterweight to help raise the pestle. C, a bent sapling used to help raise and lower the pestle. D, the Lazy Jim – a pestle is raised when the box fills with water, and is lowered by its own weight when the depressed box has emptied itself.

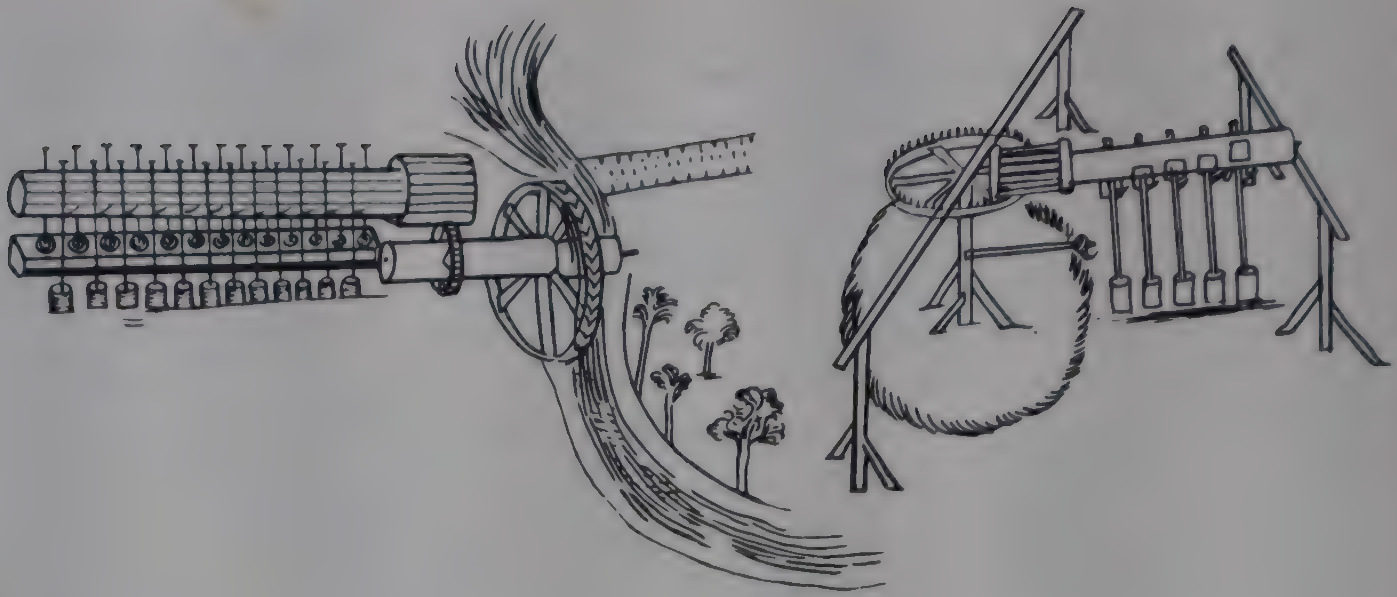


Figure 24. Patent drawings for pestle machines to be powered by animals (right) or a water wheel (left). This, the first patent granted to a person living within the confines of what is now the United States, in 1715, was intended for manufacturing "Tuscarora rice" – hominy. Though the drawings are faulty, the manner of activating the pestles is clear.

mill, in which a rotating beam activated a number of pestles (Figure 24), but Pliny describes a similar device as used by the Romans. Its action is too drastic for good grain-milling, being better adapted to breaking up ores or to cloth-fulling, where severe pounding is in order.

The full virtues of grain for nourishment and pleasant taste could not be realized so long as the whole grains were pounded to bits in mortars, and ground up indiscriminately. The meal could not be evenly ground, the endosperm was crushed and injured, the hulls mashed in with the flour. It is still a difficult problem in milling, even today, to rid the grains of their cellulose coatings without injuring the protein structure within. Ideally the skins would simply be peeled off, but the grains are too small for that, and some of the coatings too firmly attached. Some sort of shearing or rubbing action has therefore increasingly been sought as the art of milling advanced; "reduction" is substituted for mere pounding or grinding.

For this purpose the mortar was a side path, leading to a dead end, even though we occasionally find mortars approximating the saddlestone-metate form in the motions utilized (Figure 25). The back-and-forth motion of the latter made a shearing action possible, under more precise control, even when, ultimately, it would be adapted to nonhuman sources of power. Also it held the possibility of making the milling process continuous from start to finish: in time, ways would be found for feeding the grain automatically to the stones as they reduced the grain, and for removing the grist from between them. Because of their potentialities, which revealed themselves only gradually but were present from the first, this type of grinding stone became the most favored milling implement among all early agricultural peoples. In the whole of their thousands of years of use, it is probable that more grist has come from saddlestones and metates than our huge modern mills yet have to their credit.

When fully developed, saddlestone-metate combinations are true pairs; the two stones are completely adapted to each other and to the particular grinding motion for which they were used. Trial and error, observation, accident—these certainly played a part in this development, but the intellectual factor should not be minimized. In the case of the mortar and pestle, the tool forms were final and dictated the manner of their use, and thus were not capable of progressive evolution: brass mortars and pestles of today are not different, functionally, from their prehistoric stone prototypes. But in the saddlestone and metate combinations, the tool forms were improved by motion analysis, however crude, and by some attention to work conditions. While we find mortars of almost all sizes and descriptions, including large ones which certainly would be monstrosities if used for milling, the saddlestone and metate everywhere tend to be approximately 15 inches long, more or less, by 10 or a dozen inches wide. And everywhere, with the true saddlestone or metate, the position of the worker tends to become uniform (Figure 26): the under stone is slanted downward away from her, she kneels behind one narrow side, usually with both her hands controlling the movement of the upper stone (like "the maid servant that is behind the mill" spoken of in Exodus), and the body moves from the hips. Very frequently there is a hollow at the bottom of the stone to collect

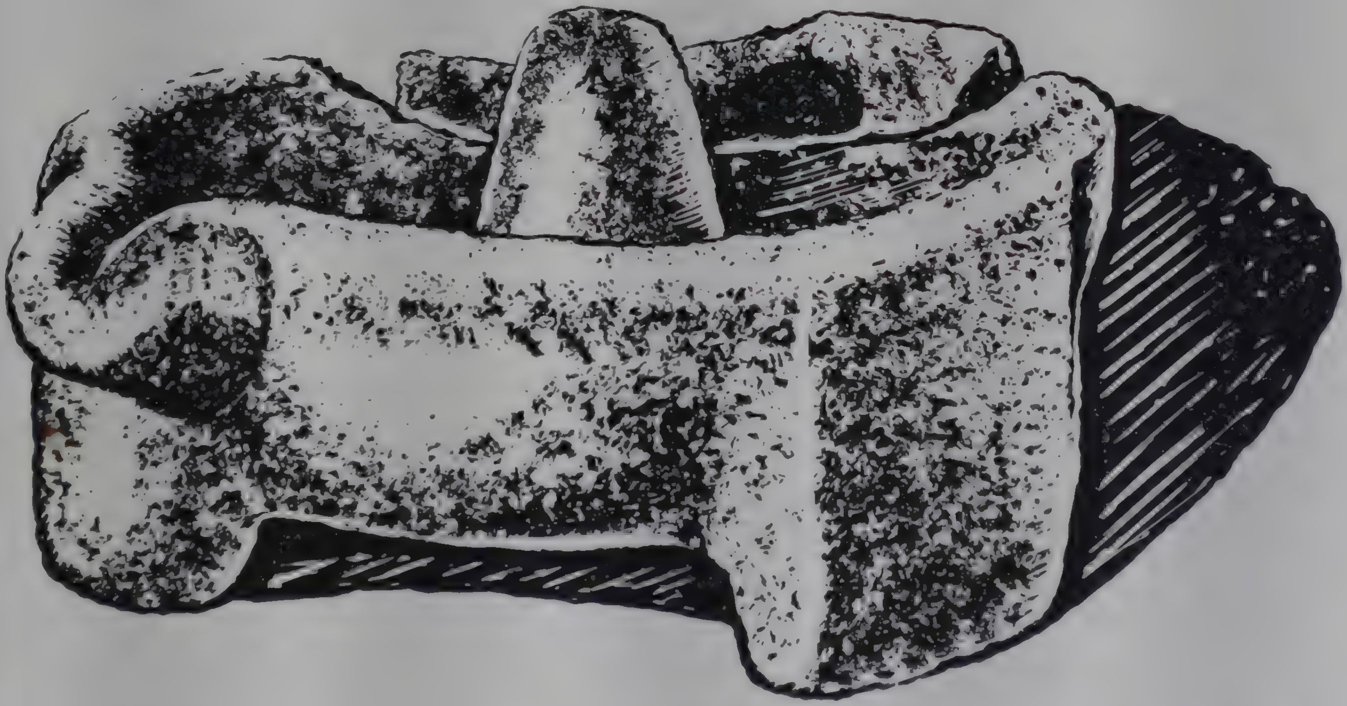


Figure 25. Mycenean mortar with legs and spout, from about 1200 B.C., found on the Athenian Acropolis. The pestle must have been worked with a motion not differing greatly from that characteristic of the saddlestone.

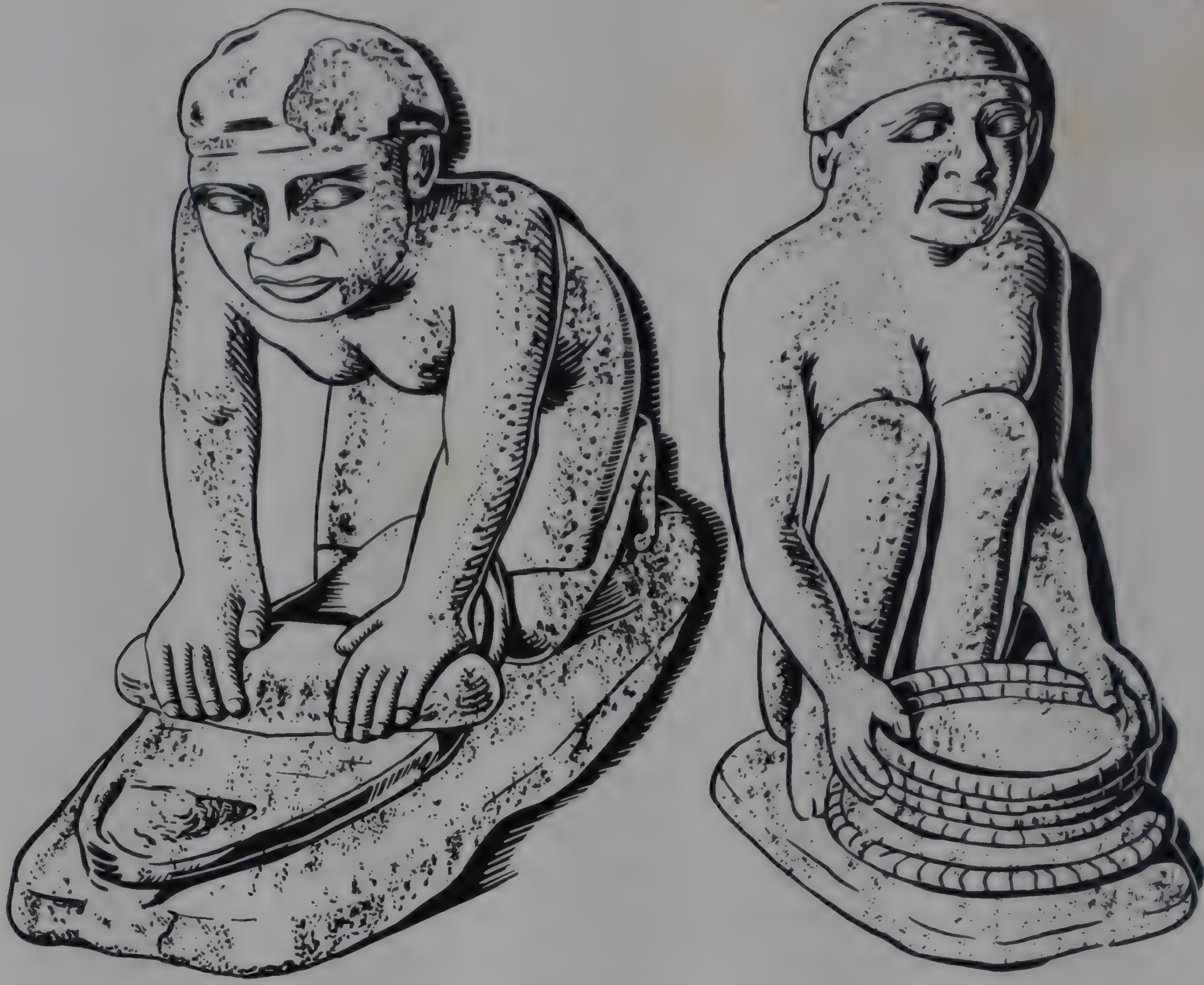


Figure 26. Egyptian statuettes from about 2500 B.C. At the left, Nebtempet, daughter of Nanupkau, grinding grain on a saddlestone. At the right, a maid servant sifting meal. Note the receptacle, at the lower end of the saddlestone, for receiving the ground meal.

the ground meal. In this case, not only the form but the work position and work movement are intentional.

The development of the saddlestone cannot be followed through from beginning to end at the present time in even a single region, owing to the fact that, though saddlestone and metate combinations are composite tools, their mated parts are seldom found together. Although in early pairs the shape of the upper stone is more indicative of the degree of efficiency achieved in the combination (Figure 5), many a rubber, and quite a few manos, have been dismissed by busy archeologists as unworthy of attention, or the stones have been classified by geometrical shape, rather than according to mode of use. A completely developed upper stone used with reciprocating motion will usually be rather long (up to 8 inches or more), not very thick, and about 3 inches wide, will have one or more flat sides, and will be of a shape easily graspable by both hands. It must be remembered, however, that many good stones were worked with one hand.

The true saddlestone can be found in Egypt as early as the Third Dynasty, not very far from 3000 B.C. (Figure 27). The lack of interest, until recently, of Near-Eastern archeologists in household utensils makes it difficult to say whether the form appears equally early elsewhere in the Fertile Crescent. Curwen suggests that the saddlestone may have been spread, along with emmer, throughout the coastal regions of western Europe by the megalith builders whose remains are found there dating from about the end of the third millennium B.C. In our Southwest, good metate forms occur at least as early, and perhaps a good many centuries earlier, than do saddlestone forms in the Old World.

The development of the saddlestone and the metate was accompanied by other improvements in processing. Because of the gentler action of these implements, it became customary to give the grain a preliminary treatment to assist grinding. In a few places the grain was mixed with sand, which

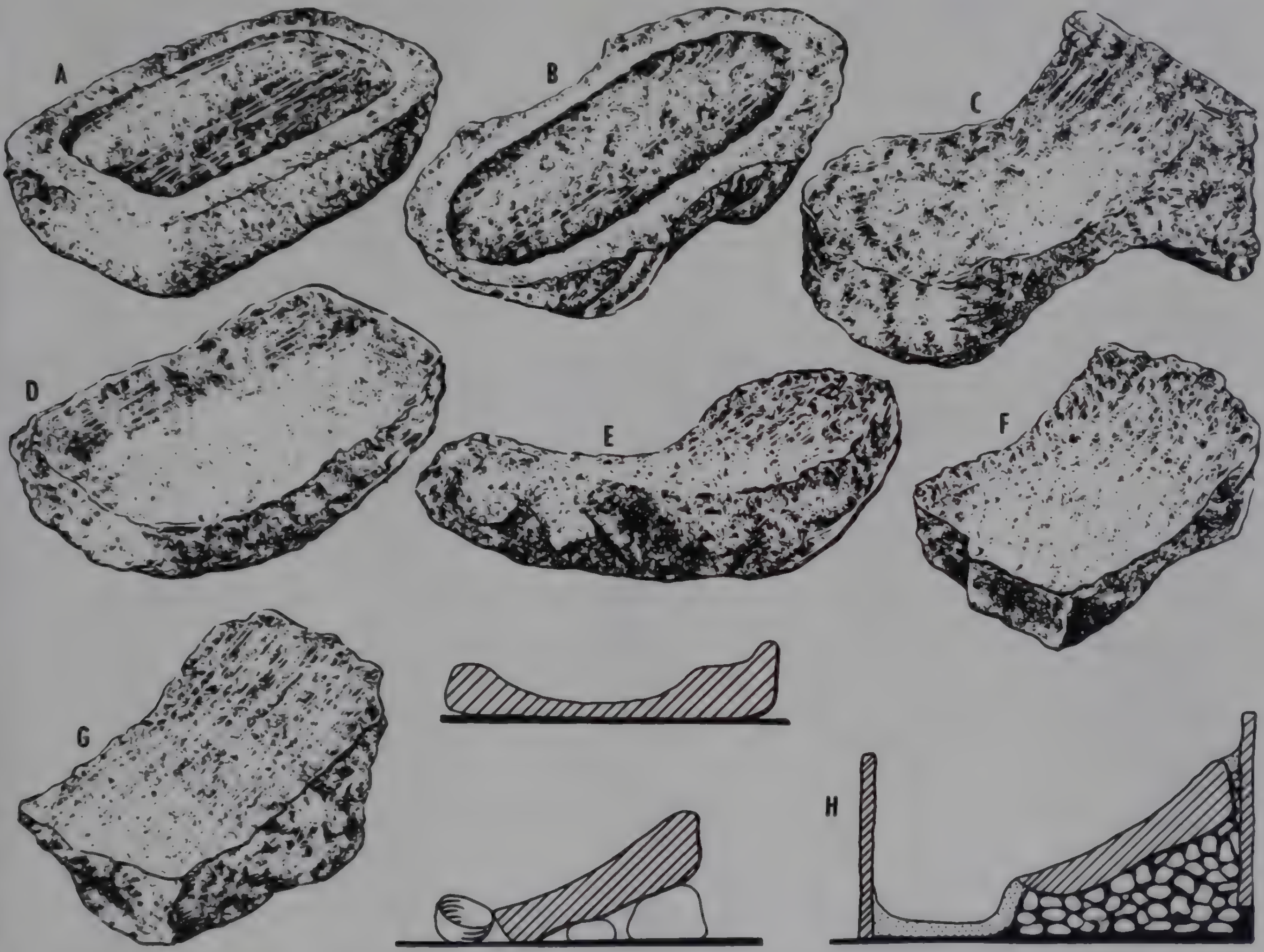


Figure 27. Saddlestones. A, Egyptian, from the third millennium B.C. B, from Mohenjo-Daro, in the valley of the Indus (same period). C, from Alishar, central Asia Minor (same period). D, from Cyprus (second millennium B.C.). E, from Delos, in the eastern Mediterranean (early first millennium B.C.). F and G, from Glastonbury lake-village, England (first millennium B.C.). H, cross sections showing development of the metate form in the Flagstaff, Arizona, region; the latest form, at the lower right, dates from the early twelfth century A.D.

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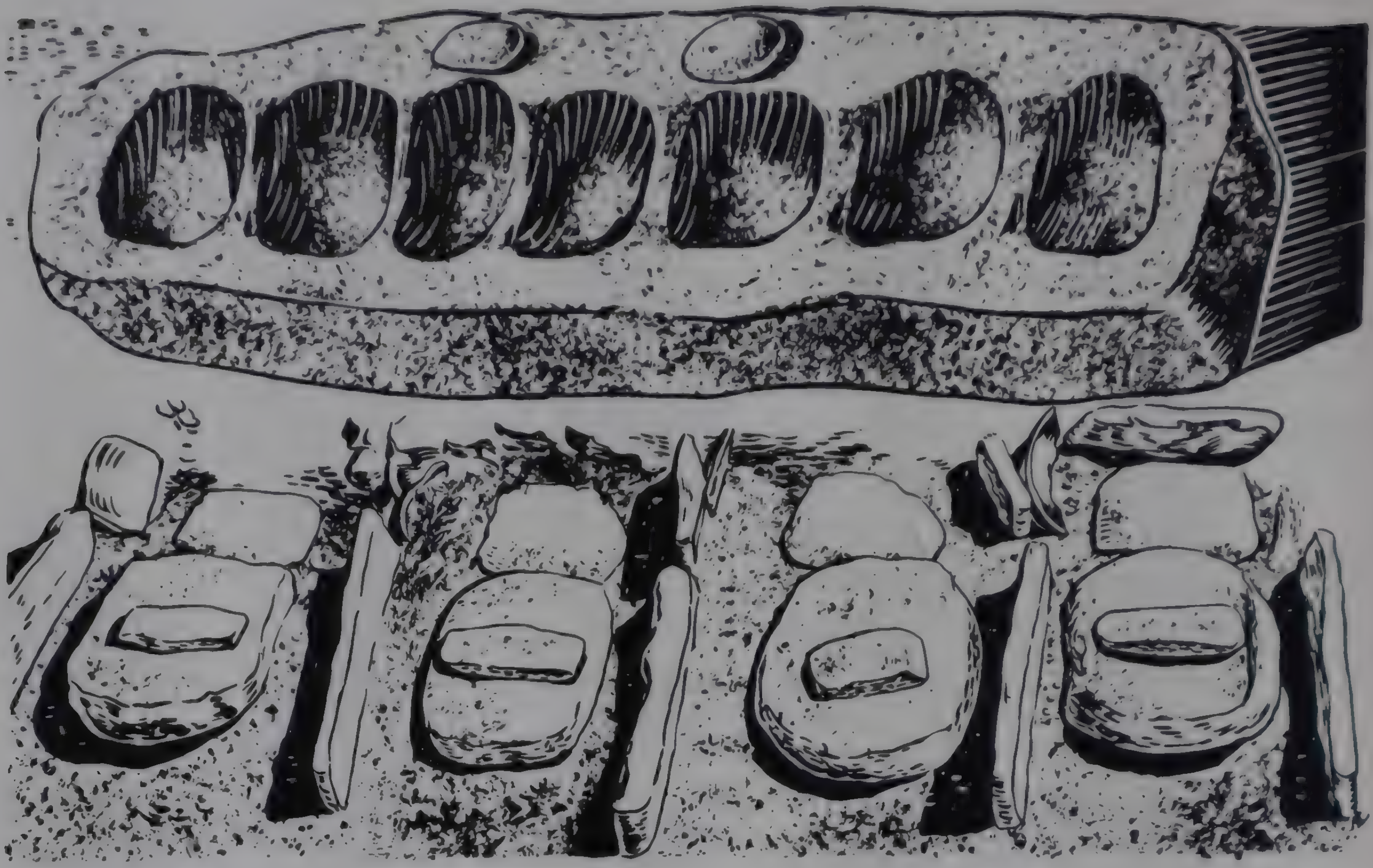


Figure 28. Below, multiple-grinding system with metates, from Point of Pines region of southeastern Arizona (earlier than the fifteenth century A.D.). Compare with Figure 29, a modern Tusayan three-stone installation. The corn was roughly ground on the right-hand metate, then passed on from stone to stone to be more finely ground. There was no sifting between the grindings. Above, Neolithic multiple saddlestone from Malta in the Mediterranean. It is not certain that this stone was used for multiple grinding; it may have been a communal stone, although the workers would have been crowded if adjoining places were occupied.

was later sifted out — with what degree of effectiveness, one hesitates to think. Or it was sun-dried, as was the custom in Rome many centuries later, or was dried by slow fires built around kilns, like the Egyptian ones shown in Figure 9. The dried grain kept better, and it also responded more satisfactorily to grinding. In some places, the grains were actually parched. Bennett and Elton describe a method whereby grain was still being parched on the stalk in the early twentieth century in remote parts of Scotland and Ireland — the *graddan* process — which is identical with that employed by the Romans as described by Pliny. By another method — the *burstin* process — the grain was heated in a kettle or among hot stones. Many Indian tribes parched their corn. It was also common practice in the Old World and the New to moisten the grain first before grinding. We have here a start of the tempering or conditioning process which has been greatly developed in modern milling.

An increased ability to control the "chop," as the modern miller calls the result of grinding, encouraged the invention of sieves to separate the flour or meal from the bran in the ground material. Sieves of many kinds were extensively employed by the Egyptians (compare Figures 26 and 34), and were made of papyrus and rushes, if we can believe Pliny. He also tells us that the Gauls made sieves of horsehair and that the people of Spain used flax. The Romans also sieved their grist, for Roman flour was divided into three grades; but we do not know as much about their sifting devices as we should like. We do know that the technique passed out of common use in the West for a good many centuries after the fall of Rome.

What the modern miller calls gradual reduction—obtaining the finished product in a series of grindings, separated by siftings—was also initiated a long time ago. In Egypt the tomb paintings show that the grain was sometimes first broken up in mortars, sifted, and then ground on saddlestones to a finer meal, which was again sifted (Figure 34). Among many tribes in our Southwest, the grain was treated on a series of metates, each of finer grain than the preceding, although without intermediate sifting (Figures 28 and 29).

As improved methods were devised at every stage in the utilization of the grains—from planting and harvesting them through their grinding on to sifting—another development of the greatest importance took place. Real bread, a leavened product, had its beginning from a marriage of baking and brewing. The connection of the two activities is shown by our

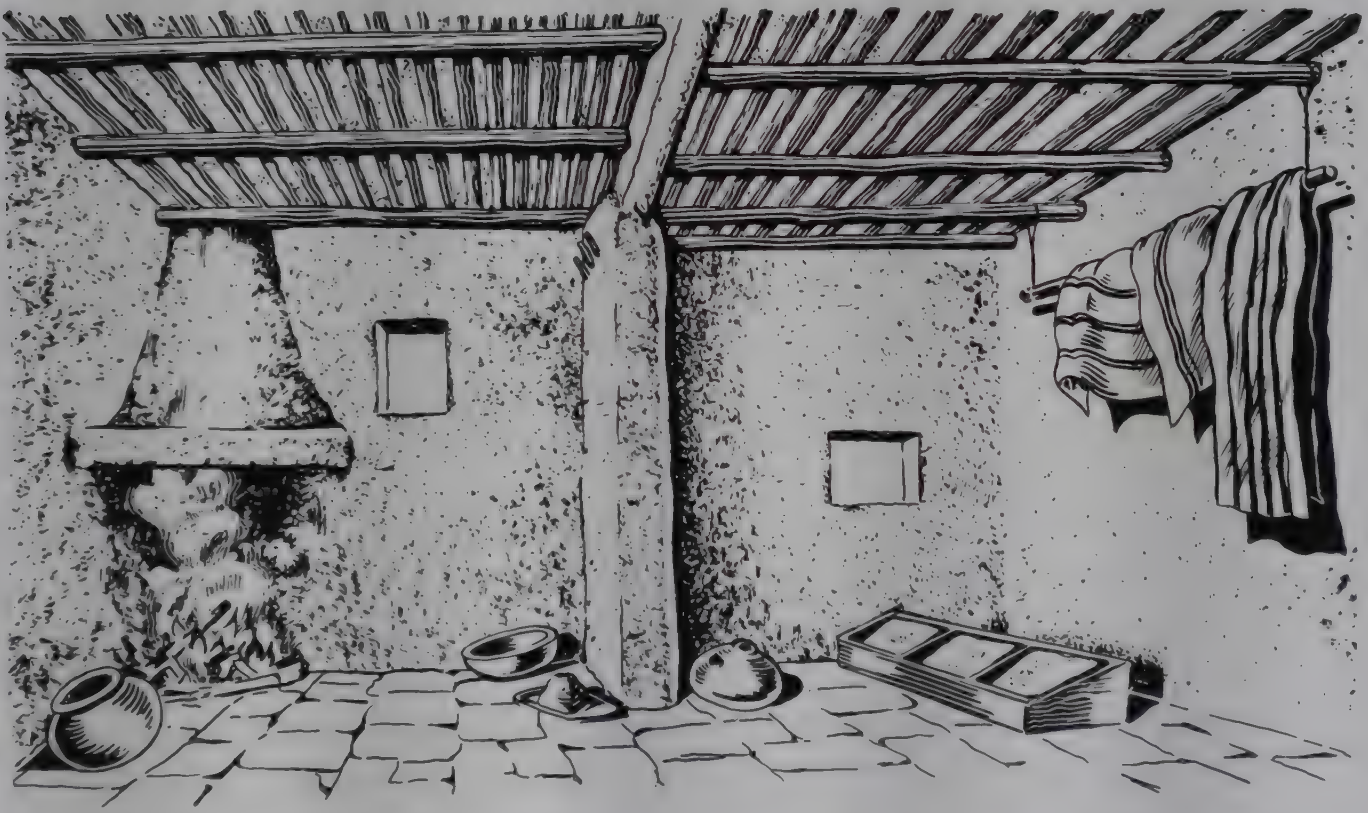


Figure 29. Modern Tusayan interior from Arizona, with a three-stage multiple-grinding metate system set up in the box near the right-hand wall. Similar arrangements, sometimes of four stages, are not uncommon among our Southwest Indian tribes, although the metate is being given up in favor of more modern milling devices.

words *bread* and *brew*, which (like *broth, boil,* and *burn*) come from the same root, whose basic idea is that of fermentation.

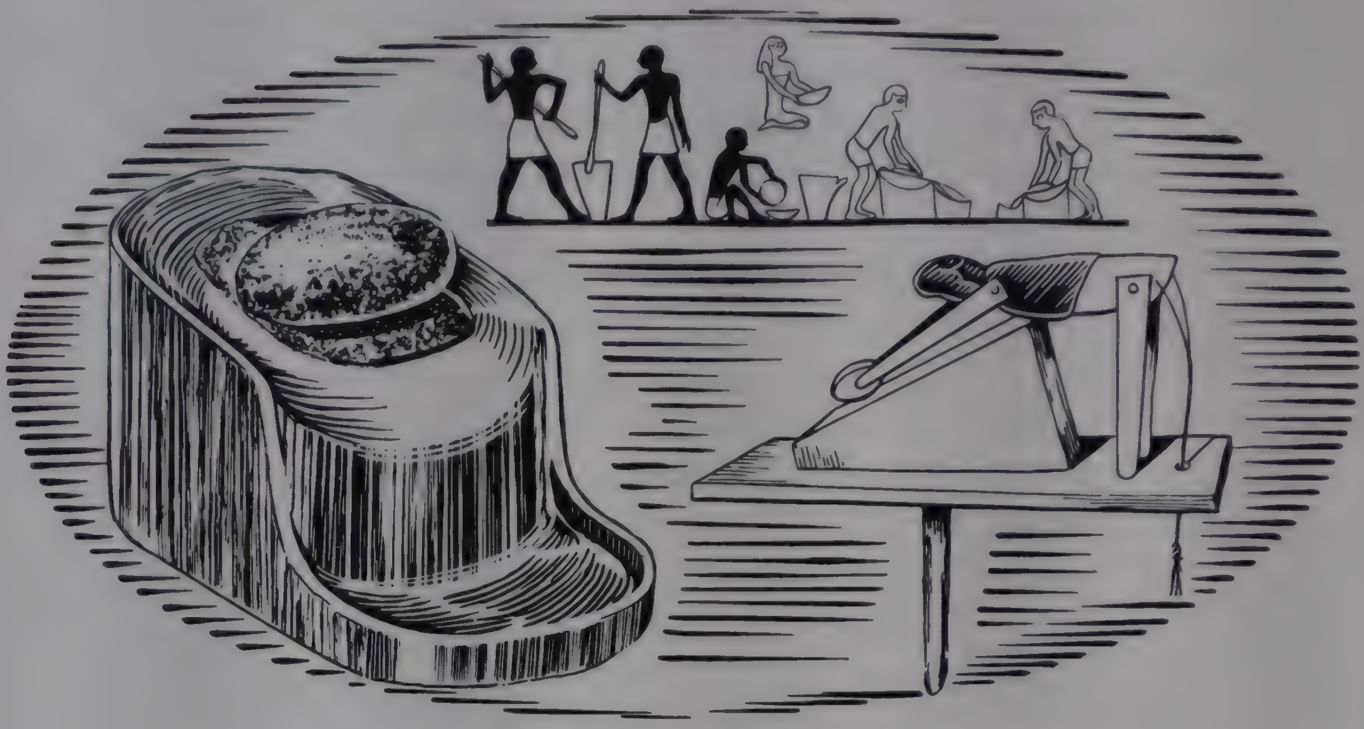
Today we know that bread dough – moistened flour – is prepared for baking by the addition of yeast, a fermenting agent; that, under the proper temperature conditions, enzymes (minute activating agents) in the yeast and in the protein of the flour act on the starches and sugars of the mixture to produce, among other things, carbon dioxide gas, which is held in the dough by its rubbery gluten, thereby aerating and expanding it; and that baking acts to fix the aerated state of the dough. To the ancients who first happened on the process, however, it must have seemed very mysterious indeed and could only have been discovered by some fortunate accident.

Where this happened, and dough was first leavened to make bread, we do not know. Nearly all peoples possessed of agriculture also brew beers or wines, whose barm, or fermenting scum, could be used as leaven. The Egyptians and Mesopotamians were certainly very early accustomed to risen breads, but the result was not thoroughly aerated, being more nearly like our corn bread, muffins, or biscuits than like the modern loaf (Oval, Chapter I). The Hebrews also used leaven after their sojourn in Egypt, although the retention of unleavened breads at religious festivals shows that these breads are the more ancient. Where barley was used – and it was still a very important food grain until comparatively late in Roman history – no true breads could be produced, since only wheat and rye contain proteins capable of sustaining enzymatic action.

Although we do not know when leavening was first used, or where, it is clear that the Romans were the first to make breads comparable to our own. They advanced to this point because of the attention they paid to flour quality, and especially to sifting. Not that raised bread was the common diet of ordinary people even in Rome's best days; it was always more or less of a luxury. But, as the oval heading of Chapter I shows, raised breads – actually rather large rolls, of which we have examples from volcano-buried Pompeii – were made in Roman times. Great as was this advance, however, we must remember that Roman bread was so heavy that it would sink in water.

The early tools of agriculture may have been crude by our standards. The early milling tools were small-scale, inefficient, domestic implements: a saddlestone worked all day producing the meal to feed a family of eight; and the loaves that were the end product may seem to us poor stuff. But in combination under especially favorable conditions, *ards*, saddlestones, and loaves sufficed to feed the hordes that soon populated Mesopotamia and Egypt and organized themselves into the first great imperial civilizations.

These nations of Egypt and Mesopotamia were grain empires: the meat of animals must have been an almost unknown food to millions of their toiling masses. They were peoples who lived in complete dependence on the fertility of their soils, and the phenomenon of annual food production out of the earth conditioned not only their social patterns but all their thinking. Later, in other lands, grain production would take its place as a basic but not completely dominant human activity; but in these river valleys it was the controlling influence on all life, and the phase of the grain empires forms one of the most revealing chapters of our story.



CHAPTER VI

The Grain Empires

> The essential part of Egypt is a green gash of teeming life cutting across brown desert wastes. One may stand at the edge of the cultivation with one foot on the irrigated black soil and one foot on the desert sands.
>
> —J. A. Wilson

THE domestication of grains and of animals, and the improvement of agricultural and grain processing methods, enabled a part of the people on the land to feed all the rest. As a result, in certain favored regions the forms of the new life pattern we call civilization began to displace the barbarism that had been universal until then; and from these centers a strong civilizing influence was spread widely, though less rapidly, abroad in the course of trade and conquest. The tempo of change was immeasurably accelerated.

Villages grew into great cities, and newly risen political states with their leader-kings absorbed the old chieftain-led tribal groups. The family supplanted the clan as the unit of social organization, enabling the individual to emerge a little more definitely from anonymity. The old tribal

Chapter head oval. Saddlestone model from Tutankhamen's tomb; saddlestone toy; tomb scene from Beni Hasan showing use of saddlestone of this type.

fetishes and totems and vaguely defined deities were briskly clarified into a formal religion of priests and temples and gods, which served to integrate and interpret the ambitions of the expanding group. More highly specialized occupations appeared, making increased use of the division of labor, and superseding the less organized productive activities of the past.

Entirely new devices and production techniques came into being: the wheel, pottery and the simple potter's wheel and kiln, weaving and the loom, the bow and arrow and other weapons, polished stone and metal implements, mining and primitive metallurgy (especially in copper and tin), formalized architecture, the decorative arts of painting and sculpture, writing, accounting, and a host of minor innovations. Expanding production and expanding needs pushed trade into distant regions, increasing knowledge and stimulating further change. Most important of all was the continuous, dynamic interplay of all these varied new forces, stimulating, shaping, correcting each other, and becoming integrated into a consistent life pattern.

The historical period, in which we can arrange events with some degree of continuity, began in these favored regions about 3500 B.C. But the changes we have listed had taken place within the two thousand years preceding that dawn of history, and they were as drastic in their impact, and as far-reaching in their effects, as any the human race has since experienced. Up to the very present we have followed avenues of progress first opened then by the creation of a superior and more adequate food supply which did not require everybody's time to produce.

Simple plow agriculture of the type practiced in ancient Egypt was approximately six thousand times as productive, in suitable areas, as a hunting economy, and freed a fifth of the larger population to follow other than agricultural pursuits (Figure 30). We haven't made anything like as great a proportionate gain in the yield of the land since then. Under highly favorable conditions, our modern intensive agriculture has succeeded in making the land less than three times as productive as it was in ancient Egypt; but this is enough to support eleven times as many people – 1,700 per square mile instead of 150 – and in certain above-average regions it has been sufficient to free 85 per cent of the whole number for other than farming pursuits.

The Egyptian rate of increase was attained only in a few regions especially adapted to continuous cultivation with the plow. Hoe agriculture was only three times as productive as food-gathering, and the hoe was all that could be used in many other parts of the world. Primitive plows were adapted only to loose, arable soil, and at first only to extraordinarily fertile soils or soils that were replenished without human aid. In time farmers would learn to practice crop rotation, fallowing, deeper tillage, fertilization by turning cover crops under – "green manure" – or animal manuring; and then continuous cultivation of less fertile soils would become possible, while improved wheat strains would allow grain cultivation to migrate northward.

But until these arts were learned through practical experience, large-scale grain-growing was possible only on extensive, deep, well-watered loess areas, where the loose, fine, wind-deposited earth possesses a long-lasting but ultimately exhaustible fertility, and on the self-replenishing floodlands of great rivers flowing along not too steep gradients from ample sources — snow-covered mountains or extensive lakes. Soil of the first type was rare in the regions where wild barley and wheat were first cultivated: the great loess areas of Inner Asia, Russia, and central Europe were far distant. But the river systems of Mesopotamia and Egypt were being formed during the postglacial period when the pluvial belt was moving

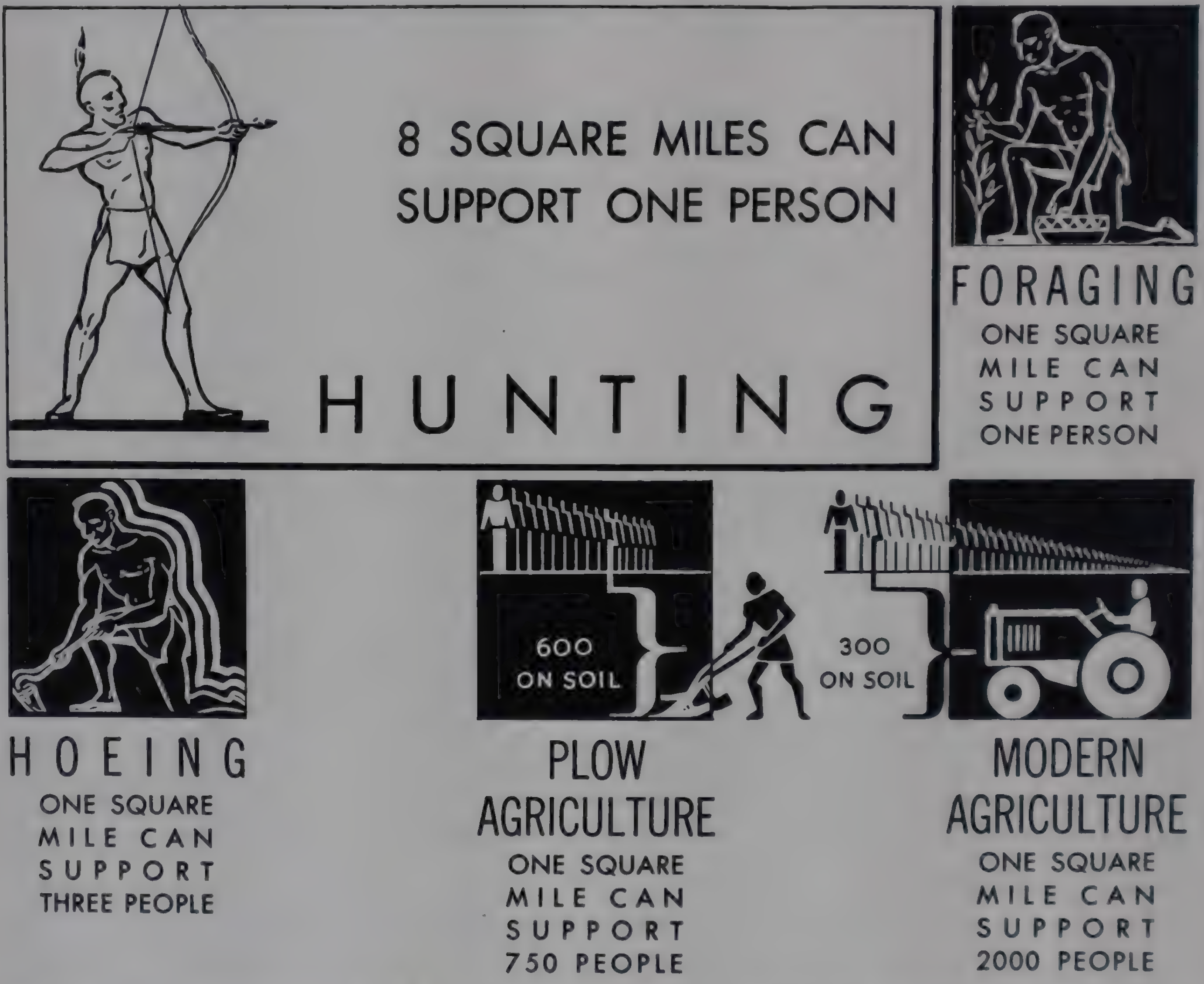


Figure 30. Comparative chart of subsistence areas, showing the number of people that given areas can support under various conditions. Basis of estimates: *hunting* — Plains Indians before the coming of the white man; *plant foraging* — California Indians before the white man; *hoe agriculture* — Eastern Woodlands Indians before the white man; *plow agriculture* — ancient Egypt; *modern agriculture* — highly developed regions in the United States today. The comparisons made in the text were arithmetically derived from the data in the chart.

northward, and the lands of these flooded valleys would maintain their fertility during thousands of years of constant cultivation.

As rainfall decreased on the borders of the present North Arabian Desert, some of the semiagricultural nomads living on the advancing desert fringe were impelled to migrate to better-watered areas, taking with them their primitive knowledge of grain cultivation. Some moved to the east, first into the upper valley of the Tigris, where Assyria would later arise, and then as the Two Rivers area became habitable, they moved down into its swamplands. Other groups from the same desert fringes drifted southward, and eventually reached the Nile Valley. We cannot be sure whether these grain-growers arrived first in Mesopotamia or Egypt; but the evidence does indicate that those who came to Mesopotamia were somewhat more advanced: their pottery was better, and they had copper, it seems, from the beginning.

Probably a little before the middle of the fourth millennium B.C. the Sumerians, a broad-headed people of the so-called Alpine race, moved into the Two Rivers area from the east and mingled with the long-headed earlier inhabitants and some Semitic-speaking peoples from the west. This blending of races and cultures was immensely stimulating, as it has so often proved in history. Here was an amazingly fertile soil, possessed by a composite people whose minds and arts were equal to making the most of it; and on a basis of grain agriculture arose the first civilization anywhere in the world. Great cities were built – Uruk came to cover two square miles – and within their walls huge temple structures rose to the skies. These people used the arch in building, they had metals and the wheel, and they made cylindrical seals and devised pictographs, the first form of writing.

The Nile Valley had its turn only slightly later. During three predynastic periods the governing power of the whole country was centralized, copper became plentiful, and foreign contacts were made, even with the sister civilization of Mesopotamia. Then, toward the end of the fourth millennium B.C., the historical period dawned with the First Dynasty of the Pharaohs.

Almost the only natural advantages Egypt and Mesopotamia had to offer the early settlers were first-quality farm lands, plus very useful rivers. Both regions are hot in summer, Mesopotamia a raging inferno. Neither valley yielded metals or had many useful plants, except the papyrus in Egypt and the date palm in Mesopotamia. Neither possessed timber, although the stem of the date palm has limited uses. Egypt had stone for building, but stone is so rare in lower Mesopotamia that we can be sure that even the smallest rock has been imported. Egypt is virtually rainless, except that the delta country has occasional winter showers, while Mesopotamia today has an annual rainfall of seven inches (mainly in the winter) and probably had little if any in early times.

Rivers are the wealth of these regions, as they are put to use by the ingenuity and labor of man. Egypt is the more fortunate, because the Nile is amazingly dependable in volume and timing. From mid-June to mid-October was the season of *Akhet*, or "Inundation," when the river rose and filled the great banked basins the inhabitants had built along almost its entire length to trap its waters. Nowhere, except in the delta, is the distance from river to desert more than about ten miles. The basins, some of them covering 40,000 acres, held their water for weeks, depositing its fine, rich silt at the rate of four inches per century. By mid-October the water had been dropped by lower levels back to the river, which was again within its channel.

From mid-October to February was the second season, *Perit*, or "Coming Forth" (from the inundation), and during this time the grains were sown. There was very little evaporation during these winter months. Then followed the season of Shemu, or "Harvest," from February to June. Osiris, chief of the Egyptian gods, god of grain and of the underworld, was ritually slain each year on about November 11 to 14, as the seeds went into the ground, and he was reborn each year in the harvest of the following April (Figure 31). Thus Egyptian life moved to a majestic, unvarying cycle of seasonal events, undisturbed by the vagaries of weather that so often disarrange other peoples' plans and programs.

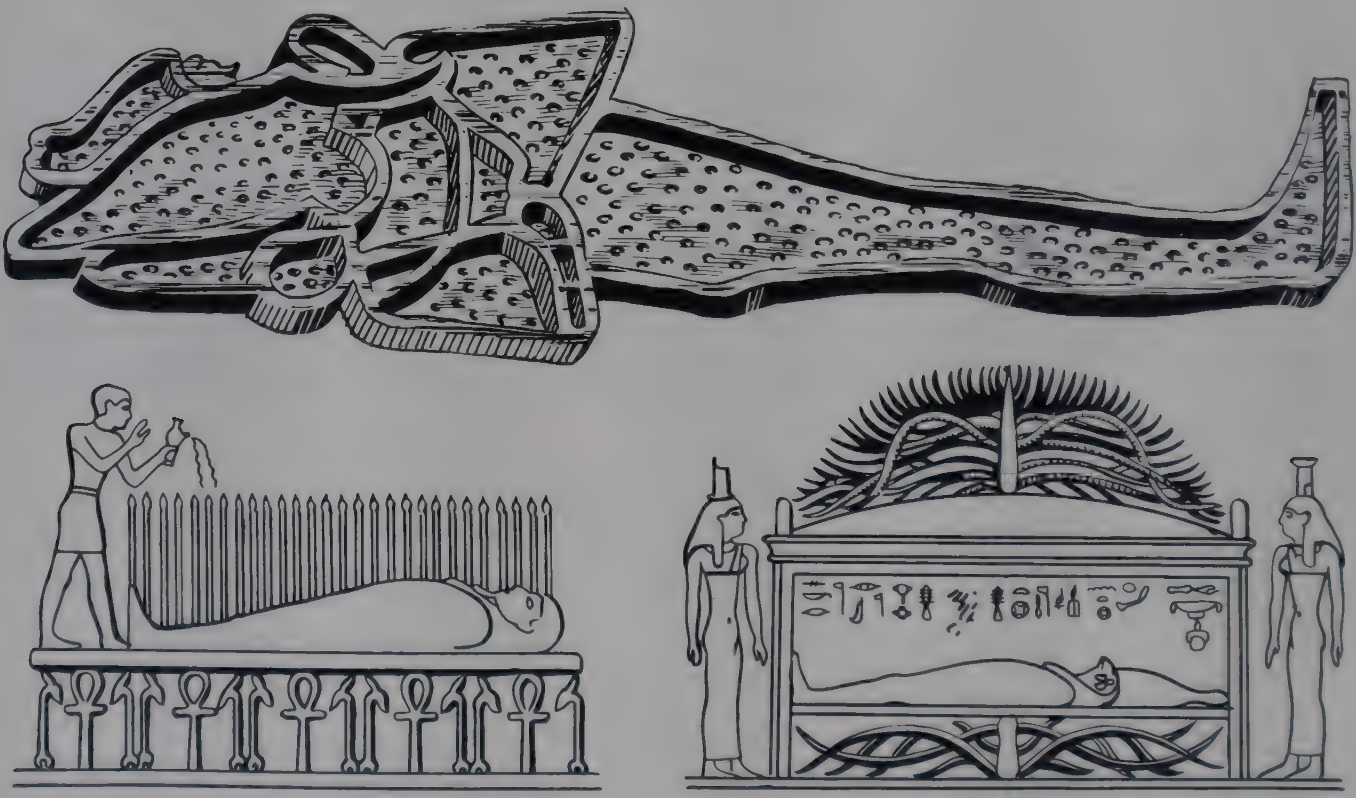


Figure 31. Above, germinating Osiris form from the Eighteenth-Dynasty tomb of Tutankhamen (fourteenth century B.C.), which was filled with earth and grain seeds so that Osiris might sprout into life. Below, the annual vegetative resurrection of Osiris as shown in tomb depictions: at the left, from Philae; at the right, from Dendera.

The Tigris and Euphrates were not so accommodating. They were in flood in May, and back within their banks by June, with summer pouring its heat on the land. By July any bare ground would be parched if it were not artificially watered, and this the Mesopotamians in time managed by means of an intricate system of numberless canals. From these canals the water was raised, laboriously, onto little fields, often of no more than two or three acres.

Enormous effort was required to build and maintain the canals and raise the water to the fields – effort always threatened by the capricious streams, with their unpredictable floods and dearths and frequent changes of course. The countless channels were easily clogged, and worst of all, the river silt was dangerously alkaline. The Nile beneficently scoured out its valley every year, whereas in Mesopotamia the water leached the salts out of the soil and destroyed its chemical equilibrium. Silting spelled ruin in Mesopotamia if its harm was not corrected. After the Mongol invasion in A.D. 1258 the country deteriorated not because the irrigation systems were destroyed but because of lack of maintenance and carelessness in their use. Since then Mesopotamia has never recovered its former fertility and prosperity.

Yet in ancient times, in spite of the difficulties that had to be overcome, the land of Mesopotamia was made amazingly productive. It would support two crops a year under favorable conditions. Herodotus (who knew Egypt also) tells us of Mesopotamia that "of all the countries we know there is none which is so fruitful in grain," and he says that under the most favorable conditions the yield reached three-hundredfold. Though an obvious exaggeration – it implies yields of over 700 bushels per acre – Herodotus' statement indicates the enormous fertility of the region; his exaggerations elsewhere are never even remotely so heroic.

In Egypt some 10,000 to 12,000 square miles were cultivated, from Assuan to the sea – about the same as today. This was comparable to the extent of cultivation in the Two Rivers region, although the total alluvial area there was almost three times as great. In both countries barley was long the standard food of the common people – who of course were all but a small fraction of the population – not because they liked it better but because it was easier to raise, yielded a bigger crop, and therefore was cheaper.

The mental attitudes and modes of life of the ancient peoples of the two great river valleys were directly conditioned by the circumstances amid which they lived. In their world practically all work was done by human beings or by animals, in highly organized effort which depended directly on the cooperation of powerful manifestations of nature – the rivers' behavior and the action of water, the fertility of the soil, the growth habits of plants and animals, the succession of the seasons. We see these phenomena as the palpable workings of physical laws, but ancient man interpreted his environment in terms of his own nature, and acted accordingly. The gods were everywhere in the natural world, being it or animating it; they were strong and clever, and they kept a man guessing, but they were not essentially different from oneself, not omnipotent or omniscient. They could be, and must be, cajoled or coerced. The religions of Egypt and Mesopotamia were all-embracing, penetrating and controlling every phase of men's activity. And the more important the activities, the more ritualistic they became.

None was more vitally important than the raising and processing of the grain on which life itself depended, and none was more fraught with mystery. In both regions the ritual of agriculture and its practical technique were inseparable. Religion thus became an eminently practical discipline, keeping both the earth and the heavens in order; in Egypt this order was stable, and its institutions acquired a kind of static adequacy which enabled them to persist unaltered for ages. In Mesopotamia conditions did not allow any such placid permanence, and this difference in circumstances was the cause of a radical divergence between two civilizations which were dominated by a similar concept of the relation between man and the powers of nature.

In Mesopotamia, because of the rivers' capricious and often destructive behavior, chance seemed to rule the world, and there was no certainty in the future, and no building for it. As a result, Mesopotamian civilization was literally written in the dust. Great quantities of baked clay accounts and messages have survived, but of pictorial records and artifacts relating

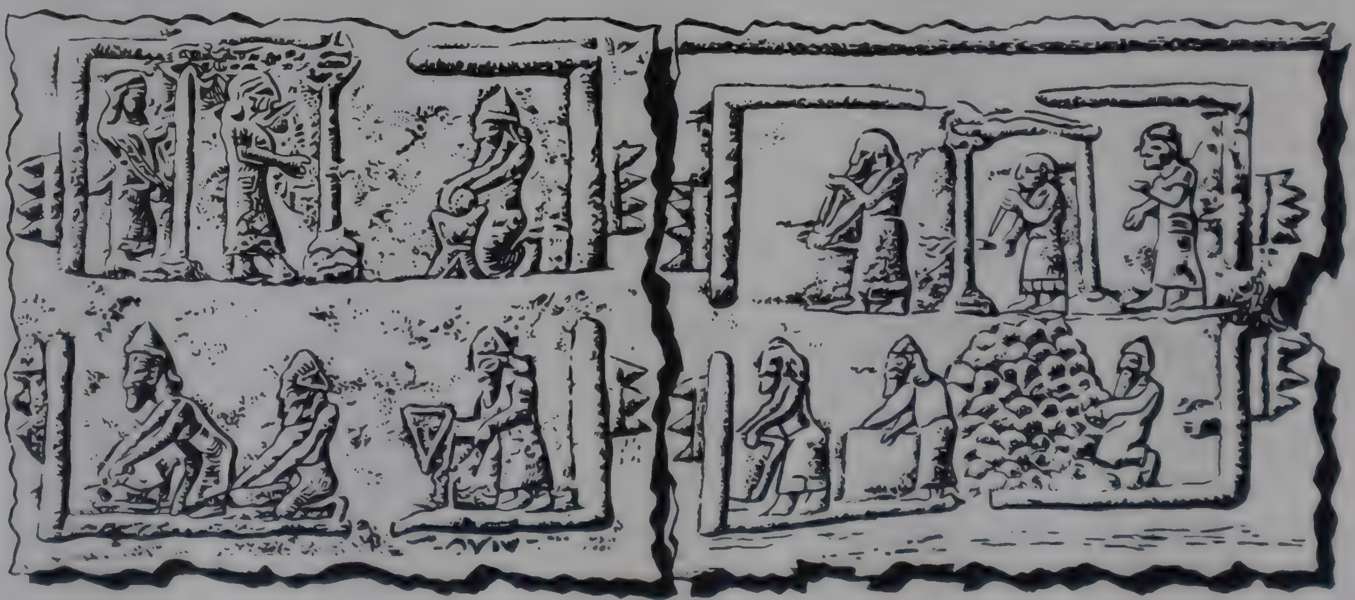


Figure 32. Bronze reliefs showing kitchen activities, including the making of bread, being carried on in the camp of Shalmaneser III of Assyria (ninth century B.C.). The two figures at the lower left are grinding grain on saddlestones. At the lower right is a heaped-up pile of bread.

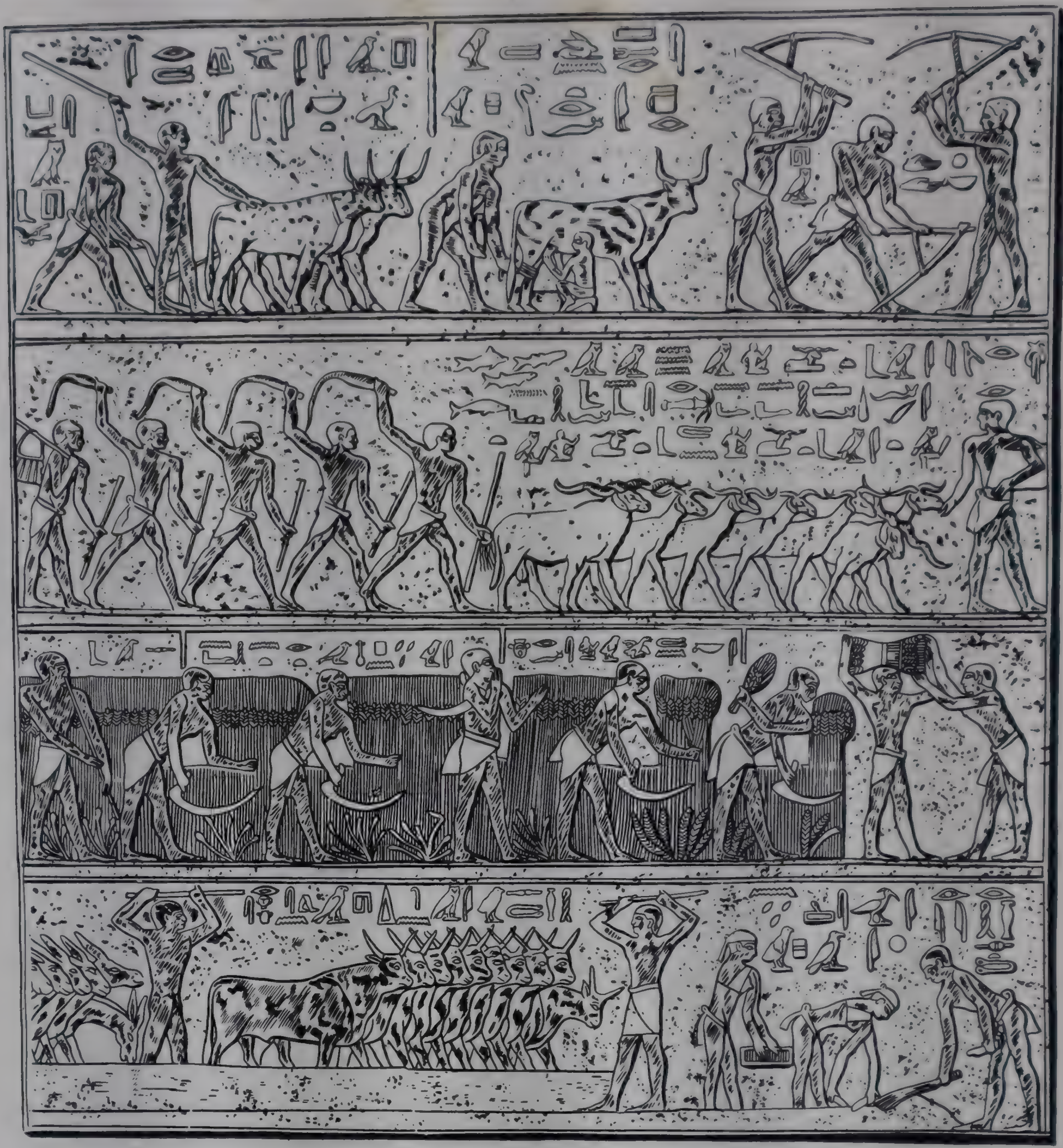
to humble occupations we have astonishingly little. There are the plows, mortars, and saddlestones we have already mentioned (pages 40ff), and we have a scene of breadmaking (with the saddlestone), as well as other kitchen activities, purporting to show the camp of Shalmaneser III of Assyria in the ninth century B.C. (Figure 32). But we cannot watch the Mesopotamians following their common routines as, in striking contrast, we can watch the Egyptians.

In the Nile Valley, the clocklike regularity of the river's phases, and the extreme dryness of the climate, with the resultant absence of erosion or weathering, fostered an assumption that all things were or might become eternal, including man's own body. Stone was abundant. So the great, who had the power to prepare for this attractive eventuality, built some of the world's most enduring structures as domiciles in which their bodies could await the souls' reunion. They furnished these long homes symbolically with comforts and treasures, images of guards and slaves, and depictions of all life's good activities of work and play, to wait until they should be needed by their resurrected master. In that future, food production and food preparation would be of the first importance. Consequently, the tombs of great lords were furnished with paintings, reliefs, and models which allow us to watch, with almost cinematic clarity, the Egyptian workers going through the successive stages of these labors.

For this kind of record the Egyptian artist perfected a highly stylized vernacular, a form of pictorial writing. For each labor or motion he chose one or two typical poses, that showed exactly what was being done, and these he repeated throughout a group without any effort at individuation. With these technical resources he could tell a story of daily life with the utmost precision of detail. In an early tomb like that at Sakkara, built by Ti, who was chief architect of the solar temple and hairdresser royal near the beginning of the Fifth Dynasty, about 2600 B.C., the mural reliefs cover great, pagelike spaces with their story, and above the horizontal rows of figures are carved hieroglyphic texts as human and colloquial as the "balloons" of the modern comic strip.

On the walls of one room, the Ti murals relate the activities that take place along the lowland banks of the Nile between inundations — the profitable sports of fishing and hunting; the still more profitable labors of planting, harvesting, threshing, grain storage, grinding, and baking. From these murals, and from others in the tomb of Mereruka, of about a century later, we have abstracted a series of scenes and arranged them consecutively in Figure 33 to tell the story of the growing and harvesting of barley.

The soil of Egypt was so soft and rich, especially just after the flood, that it was necessary only to sow the seeds broadcast as the worker at the right of the second row in Figure 33 is doing, and cover it by one of three methods, all shown here. The seeds might be turned under by means of a



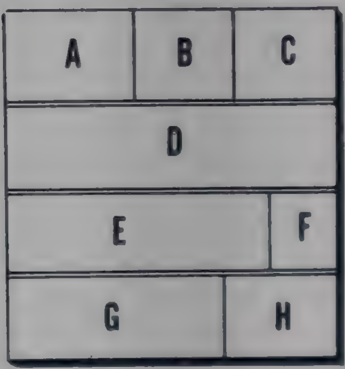


Figure 33. Barley-growing and harvesting scenes from the Fifth-Dynasty tombs of Ti and Mereruka, 2600–2500 B.C. The key at the right identifies the scenes, as follows: A, planting with the plow. B, an escapade in the fields. C, planting with the mattock hoe. D, stamping in the seeds with a flock of rams and ewes; the sower is shown at the right. E, reaping the barley. F, placing a sheaf on a worker's head to be loaded on donkeys. G, using cattle to thresh the grain; at the left, partly shown, donkeys are being used for the same purpose. H, winnowing the grain by three methods – by sieve, winnowing fans, and broom.

light plow, the only kind used in ancient Egypt (Scene A). The hieroglyphs at the left of the plowman say, "Covering [the barley] by means of the plow," and above the animals is the driver's cry, "Get along! Look below, you workers!" – no doubt a demand for a good, straight furrow. Next, one of the draught animals – a cow – is being surreptitiously milked by a child, or perhaps by a man drawn small, after the Egyptian fashion, so as not to interfere with the outline of the cow. The milker's accomplice is warning him, "Milk away! Hurry before the field-worker comes!"

In Scene C, three men are burying the seeds by means of hoe-plows, or mattocks, like that shown in Figure 13. This was the method resorted to where a plow could not be maneuvered easily, as on higher ground. If the soil was still quite wet at planting time, the seeds could be trampled into the mud by driving over them herds of donkeys or cattle, or, as in Scene D, rams and ewes. One of these is eating from the hand of the sower – probably a means of leading on the bellwether of the flock. The sower, looking back, is singing to the herdsman an admonition of what may happen to them if they waste time on the fishes – fish were symbols of the West, the Land of the Dead: "The field-worker is in the water among the fishes. He mixes with the catfish, he exchanges greetings with the oxyrhynchus. West! Where is the worker – the worker of the West?" This song gives a vivid indication of the aquatic conditions under which the planting was taking place.

After planting, there was little to do in the fields until harvest time. In Scene E barley is being reaped by grasping a handful of stalks at waist level, and cutting them off with the sickle just below where they were held. Each handful was laid at the worker's feet with the heads in the reverse direction of the preceding handful, to allow binding into a neat sheaf. The line of reapers moves to the rhythm of a piper or flute player at the left, and someone comments, "This barley is good, and there's a lot of it, friend." One worker has paused, with a hand to his mouth, and seems to be calling (in the last group of characters to the right), "Where are you, hot-hearted youngster?" Perhaps he is addressing the first worker in the line, who is out of rhythm. Or perhaps he is merely spitting on his hands, in the immemorial fashion of manual laborers.

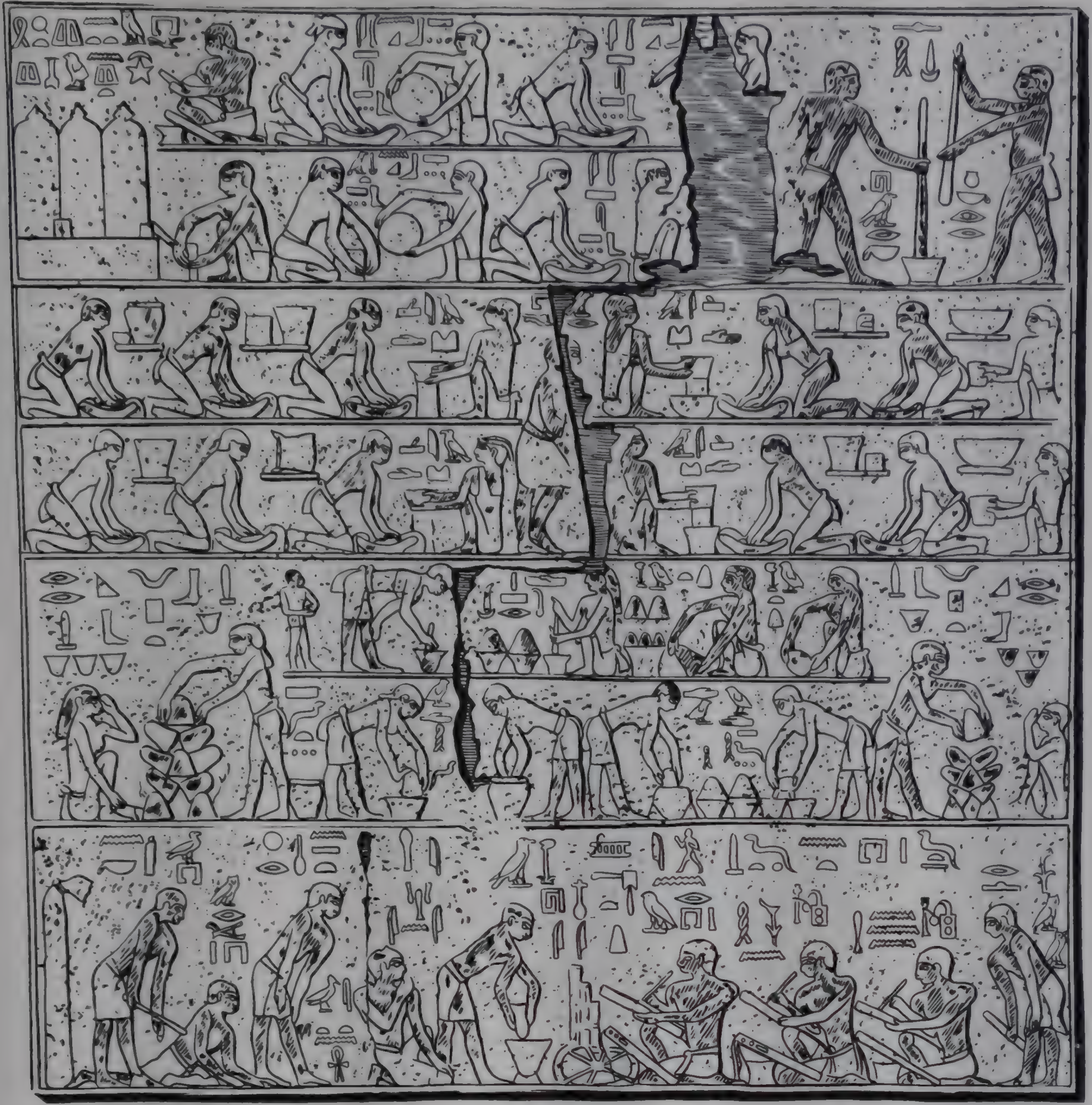
In Scene F a sheaf is being placed on a worker's head, to be carried to a rapidly growing pile. We have omitted a number of scenes showing sheaves being loaded high on donkeys' backs for transportation to the threshing floor, although these are among the most animated of the series. The sheaves were loaded in nets, which were slung across the animals' backs, so that a delicate job of balancing was called for. Evidently the beasts were as exasperating then as they can be today, because the language in which the workers are berating them can be translated, according to Montet, only with the help of certain anatomical and medical treatises that have come down to us. There are tomb inscriptions which say that more than two thousand donkeys were used to carry in the master's grain, which gives some idea of the magnitude of the farming operations of that time.

On delivery at the threshing floor just outside the village, the nets were unloaded from the donkeys' backs, the sheaves removed and opened, and the heads of grain spread evenly over the hard, smooth dirt floor. Then herds of donkeys, goats, or oxen were driven over them to trample out the grain, as is depicted in Scene G. Over the oxen is an inscription giving the overseer's orders, "Get close to them! Make them go to the center of the floor!"

After threshing, men piled the loose straw into high ricks, which were then tied up with papyrus rope, while at the same time the grain was winnowed from the chaff by a group of women, who enter the activities for the first time and are shown in Scene H. At the right a long broom or sweep, made of withes or reeds bound together, is being used to stir the heap so as to bring the coarser straw to the top. The woman in the center is picking up grain and chaff with a pair of winnowing fans — concave, paddle-like scoops — which she will lift high over her head before emptying, so that the breeze will blow away the chaff while the grain falls straight down. The woman at the left is using a coarse sieve which retains the chaff while letting the grain fall through.

In Figure 34 we present complete the lower registers of the Ti mural dealing with milling and baking. The upper panels, depicting brewing and the making of beer pots, are omitted. In Scene A are shown in miniature the granaries in which the winnowed grain was stored. The lower figure at the right of the granaries is removing grain from one of them, while above him a clerk checks and records the quantity. The hieroglyphics above the granaries identify these workers: "The grain collector at the grain house, under the direction of the foreman of the month." At the right of this panel, in Scene B, two men are pounding grain in a mortar, to what was probably a chant that timed their strokes: the one at the left calls, "Down with it!" and the other counters, "That I do!"

In the central part of this register, Scene C, four sifters and three saddlestone operators are working together, with a helper (at the left, lower row) to apportion the grain. All of these are women, and the work each is doing is identified. The saddlestones are a primitive form of the implement, resting flat on the ground without a stand, similar to that in Figure 26. A thousand years later the saddlestones would be elevated so that the worker could be seated on a low stool, and would be fitted with compartments to hold the unground grain at the top and catch the ground meal at the bottom (Oval, Chapter VI). It is all but certain that the sifters here are putting through their sieves the coarse product of the mortar at



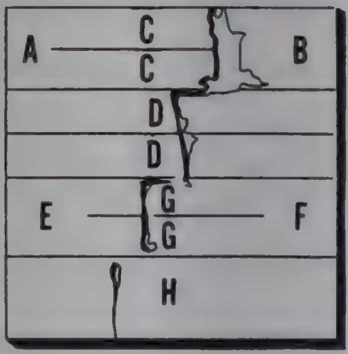


Figure 34. Milling and baking scenes from the Fifth-Dynasty tomb of Ti, 2600 B.C. The key at the right identifies the scenes, as follows: A, taking barley from the granaries. B, pounding it in a mortar. C, sieving the pounded grain and grinding it on saddlestones. D (on two levels), sieving material received from the saddlestones of the register above, and using other saddlestones on which to mix the dough; the mill superintendent oversees all the work from the center of these levels. E and F, heating the baking pots. G, preparing the baking pots for the dough, filling them, letting them bake, and removing the baked loaves. H, turning the loaves over to the office of the estate.

the right, preparatory to finer grinding on the saddlestones. They are using round sieves, similar to that in the statuette of Figure 26.

The whole of the next double row constitutes Scene D, with the figure of the mill superintendent, enlarged in proportion to his authority, in the center. Here ten women are working at saddlestones and four at sieves, the latter being identified, while two women at the right of each row may be helpers to distribute and pick up the material. From the symbols it is clear that the sifters are treating material already ground on saddlestones – note the notched pictograph for "saddlestone" at the end of each row of hieroglyphs, reading from left and right alternately. These sieves are rectangular or trapezoidal in shape. It appears that the saddlestone workers are mixing the sifted flour with a liquid or liquids (including yeast from the brewing operation above) from the jars on the shelves close at hand. From their position in the series, between the grinders above and the bakers below, it seems beyond doubt that they are kneading dough.

At the two ends of the next register, in Scenes E and F, inverted baking pots are neatly stacked for heating over fires, which are being stoked by the outer figures, who shield their faces from the heat with one hand. The inscriptions tell us that the standing figures – a woman at the left, a man at the right – are testing the temperature of the topmost pot.

Scene G covers four operations. At the upper left, two women are stirring the contents of pots, perhaps greasing them so that the dough will not adhere. Below them two women are working with the dough, while beside these, in the same row, two women are filling the hot baking pots and inverting others over them. These thick earthen jars held their heat long enough to bake the bread without being returned to the fire. Just above, two women are removing the baked loaves from the jars. All these operations are explained by the inscriptions, although the one at the upper left has a hiatus and contains obscure symbols.

Finally, in Scene H, filling the entire bottom register, we are told that the bread is "being received by the office of the estate." At the left an officer with a club bends over the superintendent of the bakery – no doubt the same individual who dominates the workers above from the center of the three upper registers. Here he is humbly prepared to receive immediate punishment if the tally is in error, but he has a "caller" standing alertly in front of him ready to speak for him. All are intently watching a fifth man, who is placing a single loaf of bread, symbolic of the baking, into a standard measure in the presence of a kneeling priest. Three scribes are taking the record in triplicate, while their helper stands at the extreme right ready with an extra roll of parchment. Figure 35 shows some of the varieties of bread made by the ancient Egyptians.

Here we see a highly organized operation based on slave labor. The position of the overseer, dominating his subordinates but abject before his

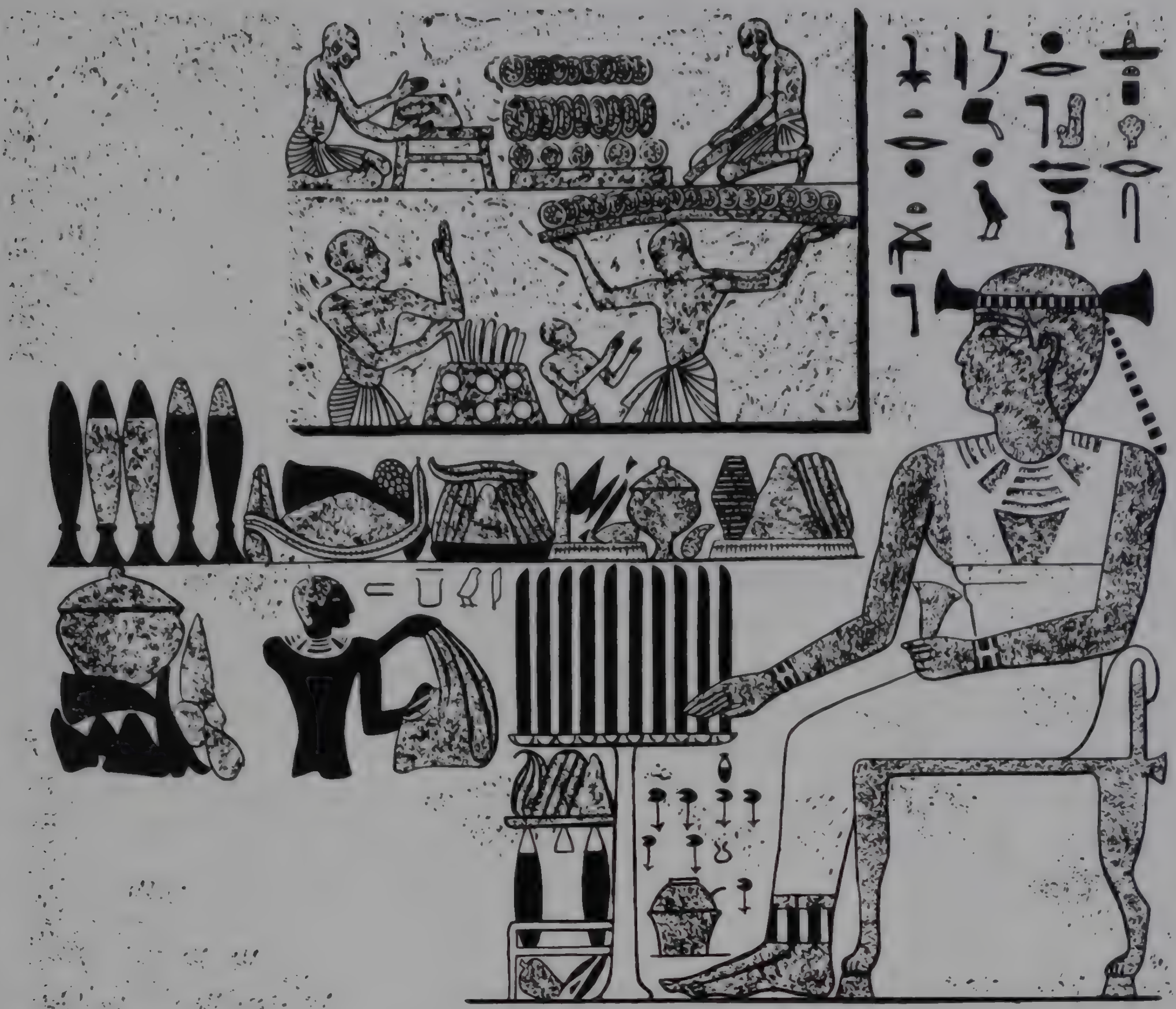
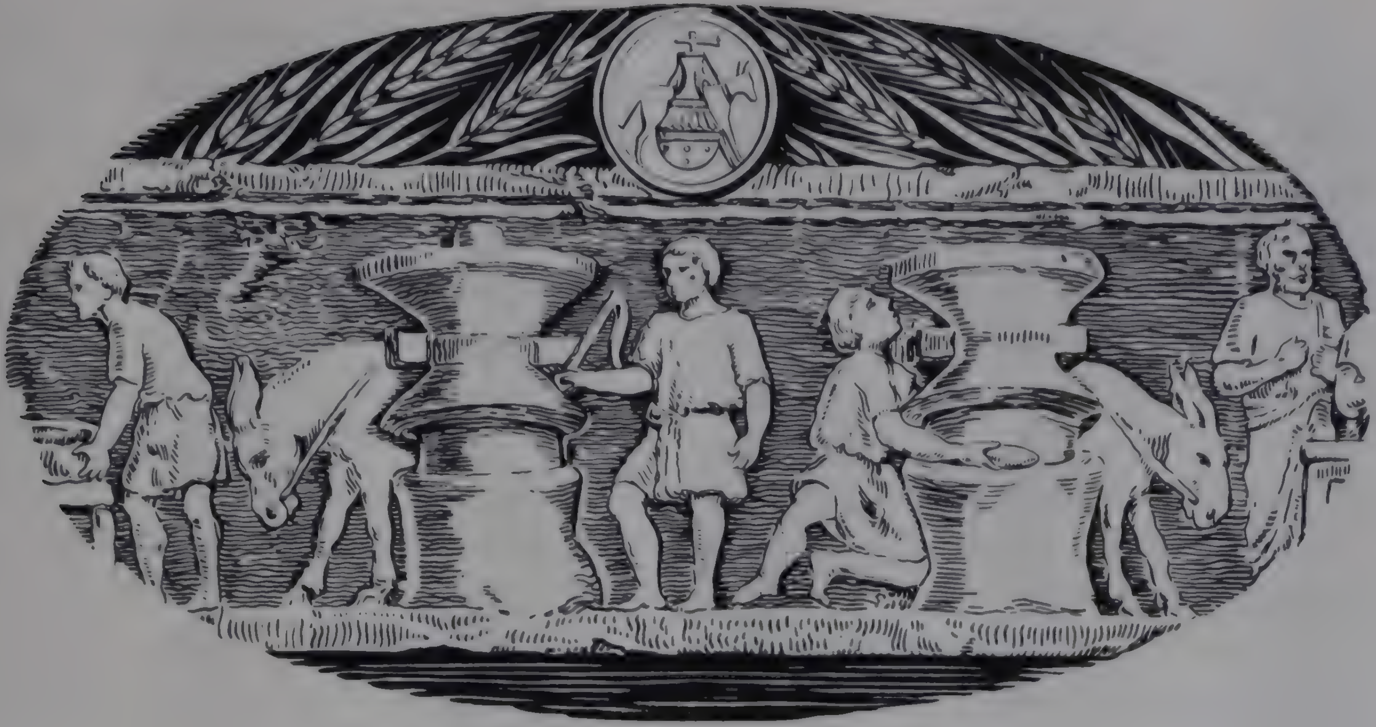


Figure 35. Some of the breads and other foods consumed by the Egyptians. Below, a Fourth-Dynasty scene (about 2600 B.C.), with the deceased seated before an altar table, on which stand tall symbolic slices of bread. This scene also contains pyramidal loaves of bread just above the altar table at the right, and jars of beer at the far left. In the insert above, cakes are being made for the court of Rameses III, of the Twentieth Dynasty (twelfth century B.C.). The cakes are being formed on the upper level, and on the lower level they are being carried to the oven, which is shown at the lower left of the insert. The six cakes are probably on a shelf inside the oven, but are shown in plan to conform with the conventions of Egyptian art.

superiors, is typical of the levels of authority in all dictatorships, even today. In Egypt and Mesopotamia both, society crystallized into a totalitarian economy. In both lands the functions of the political commissars were largely performed by the priesthoods, of which there were many; in Mesopotamia they were especially numerous. It has been estimated that in Egypt by 1200 B.C. the temples owned about one third of the cultivated land and held in slavery about one person in five. The key word of the period translates as "silence, calm, passivity, tranquillity, submission, humility, meekness." Thus Egypt moved, over a two-thousand-year period, from the strong vitality of the early dynasties to complete subjection to a police state.

The temple estates in Egypt were administered as vast manorial holdings. Those in Mesopotamia, though still large, were smaller and allowed more scope for individual enterprise. In Lagash, for instance, the goddess Bau owned 17 square miles of farm land at one time, but three fourths of this was worked by individuals in parcels of 0.8 to 2.5 acres. The ruler of Lagash himself operated 608 acres of Bau's estate. Her own temple had 21 bakers with their 27 female slaves (who undoubtedly ground their flour), 25 brewers with 6 slaves, and 40 women to prepare wool, besides spinners, weavers, artisans, clerks, officials, and priests. The temple of Bau produced goods for sale as well as for community use. For all their religious basis, these ancient systems were quite secular in their economic motivation. Industry, trade, and banking were carried on with a quite frank acknowledgment of the profit motive, as in communistic states today.

Until man acquired some respect for the rights and dignity of the individual, there was no hope that he could augment his own feeble powers by harnessing the almost illimitable powers of nature to useful work. It was a feat beyond the capacities of the ancient Egyptians and Mesopotamians. On the basis of human and animal power alone they did succeed in establishing a balance between themselves and their environment, so that the Egyptian empire was able to exist for such thousands of years that any nation of today seems a mere upstart by comparison. But the margin of energy left over from food production for other useful work, and the scope of their food-producing ritual, were not great enough to allow for the creative advances men still needed to achieve. That would be left for other, less hidebound peoples; and the great grain empires, after devising the first mechanisms of civilization based on a sufficient food supply, would reach a stalemate and disappear, the one in disasters and the other in slow decay.



CHAPTER VII

Milling Becomes a Business

> To the substitution of circular for straight motions and of continuous for alternating ones, may be attributed nearly all the conveniences and elegancies of civilized life.
>
> —Thomas Ewbank

> The cronach stills the dowie heart,
> The jurran stills the bairnie;
> But the music for the hungry wean
> Is the grinding of the quernie.
>
> —John Jamieson

IN THE first millennium B.C. and in the eastern Mediterranean, the grinding of grain underwent two momentous changes, of such importance that they marked the beginning of new directions in human progress. First, the saddlestone-rubber combination passed through a series of mutations whereby its size was enlarged and its action improved, increasing its output and requiring masculine strength for its operation. With the new equipment a man working all day could produce much more than one family's needs, creating a surplus for sale or exchange. As a result, milling for the first time became a professional activity, located not in the home or a

Chapter head oval. Rotating hourglass mills from the tomb of M. Vergilius Eurysaces, the Roman slave who became an important miller. Above, a shop sign from Pompeii.

temple enclosure but in an independent industrial establishment. Here we have not only the beginning of commercial milling but perhaps of industrialism itself, if, as seems likely, it preceded the appearance of pottery factories using the kick wheel.

The second great innovation was the application of continuous rotary motion to grain-grinding, superseding the confused or reciprocating motion of all previous milling tools. Thereafter the full strength of men and even of animals could be utilized, greatly increasing the output. More significantly, this was the essential transition that ultimately would make it possible to apply nonorganic powers to useful work of all kinds.

It was no easy thing to improve the saddlestone, since it was an ultimate implement in its own line of development. No advance beyond it could be made in Mesopotamia or Egypt, where all techniques were frozen at a workable level. In these lands no incentive to change existed, initiative had no stimulus, deviation was discouraged. Even when the innovator was the Pharaoh, in the person of Ikhnaton, he found himself embalmed and laid away at an early age by a reverent but implacable priesthood, guardians of the established ways. The early shifts toward modern mental attitudes and ways of life would occur in less static societies: in settings where life was not impossible but also not too easy, where there were difficulties to be overcome, where new social needs existed and these needs could be satisfied only by ingenuity and constructive effort. When agriculture was first imported into Mesopotamia and Egypt, those countries had possessed just such characteristics. Now the scene shifted to Troy, Crete, Phoenicia, Etruria, regions whose potentialities exceeded their present resources; to tiny, thin-soiled, poorly metaled Greece; later, to Carthage, on the edge of a desert, and to Rome, with her shallow and inadequate hinterland and deplorable harbors.

It was the Greeks who first attempted to *understand* the world – to grasp it in terms of the rational *what* instead of the dramatic *who* that had governed man's previous thinking. By this approach men would finally arrive at the skeptical, practical attitude essential to technological and scientific progress, which would regard nothing as finished or final, but would experiment constantly in search of improvement. It is a revealing fact that, although the mortar and saddlestone were the essential tools on which Egypt and Mesopotamia depended to make their grain crops assimilable, those tools were not radically changed or improved during thousands of years of incessant use. By contrast we can see, in a collection of remains from the Island of Delos, how in a few score years the less rigid minds of the Hellenic peoples appropriated suggestions from many sources, and through trial and error evolved new master forms that revolutionized milling.

Figure 36 shows only a few of the combinations that were tried; there

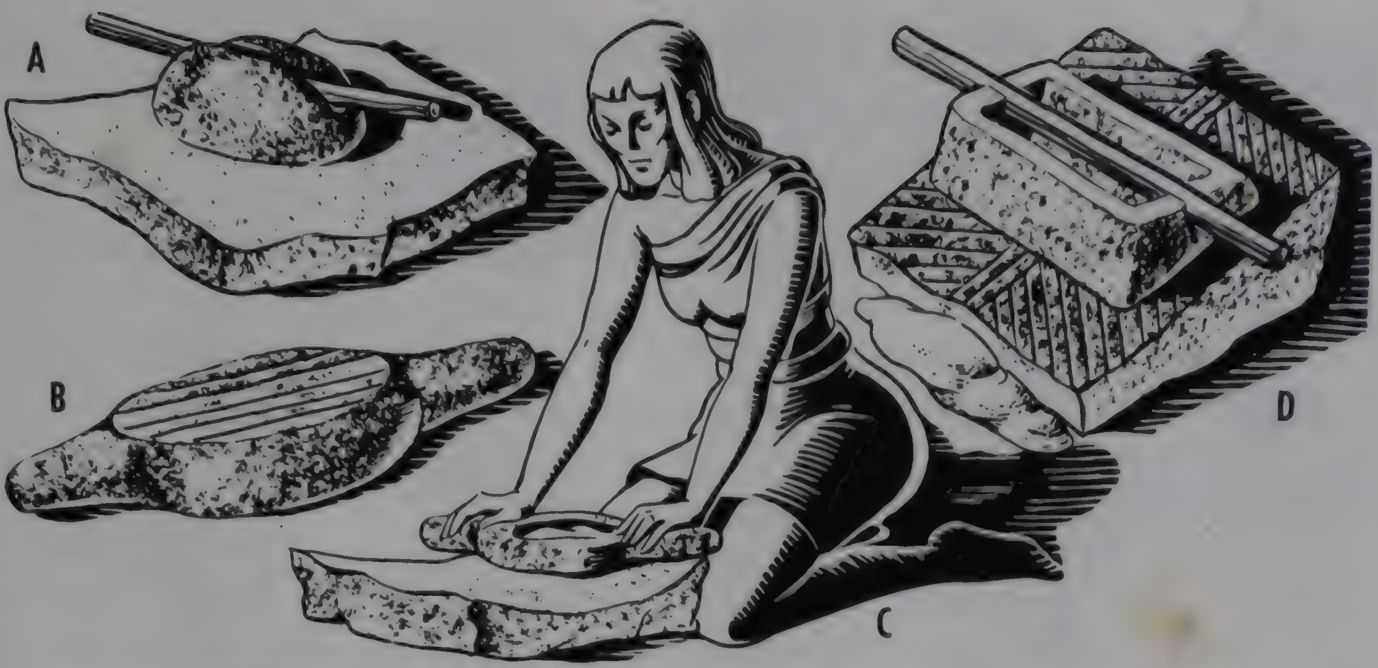


Figure 36. Milling improvements from the Island of Delos in the eastern Mediterranean, dating from about the middle of the first millennium B.C. A, a rubber with a wooden crosspiece handle, permitting use of a larger stone. B, a rubber with extension handles and dressed grinding surface, for use with a dressed under-stone, giving a shearing action during grinding. C, a rubber with extension handles and cut-in hopper, insuring greater continuity of grind. D, a mill with greatly enlarged hopper in a rectangular stone, which meets the lower stone on a slanting surface and is worked back and forth by a wooden crosspiece. A and C are slab mills; D is a push mill.

were dozens of others. Adding handles to the rubber permitted the use of larger stones and allowed the under stone to become flatter and more nearly rectangular than the usually concave saddlestone, the result being a type we shall call the slab mill. Grooving ("dressing") the meeting surfaces enabled them to hold the grain so that it would be cut open by a shearing action between the edges of the grooves, rather than be crushed by the direct pressure of the stones. From this time on it became customary to dress most millstones, and it soon became apparent that the shearing action was facilitated if the grooves were not parallel on the two stones, but crossed each other at a rather acute angle. The invention was a permanent addition to the technique of milling; even the rollers of modern mills are corrugated in this way.

Nor was this all. As the speed of grinding increased, the desirability of feeding grain constantly between the stones without interruption of the work became apparent. The larger upper stone made this practicable: a depression or hopper was cut into it, with a slot at the bottom. The length and width of the slot could be changed experimentally until a rate of flow exactly proportioned to the speed of grinding was obtained. Work could proceed more continuously, but also the decrease in weight of the hollowed upper stone allowed a further increase in its size, and this in turn accommodated a larger hopper and a further prolongation of the grinding period.

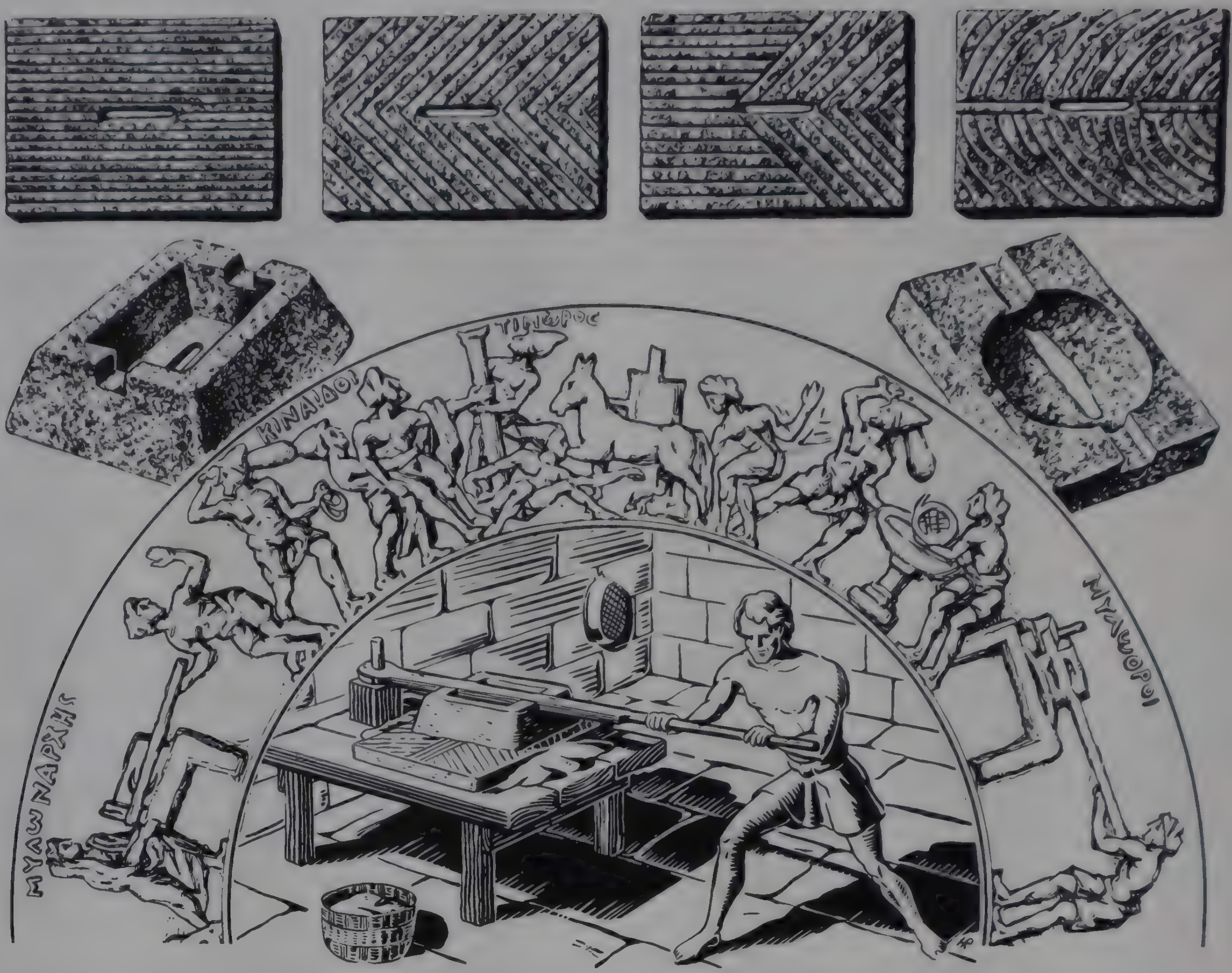


Figure 37. Lever mill. The semicircular reproduction is from a fourth-century B.C. Megarian bowl, and shows a band of revelers disturbing operations in a bakery. Two lever mills are shown, at either end of our depiction, and a single hourglass mill, behind the donkey at the top. Beneath this reproduction is shown a reconstruction of a lever mill in use. Above the semicircle, at the left and right, are shown two kinds of upper stone; at the very top of the figure appear also four varieties of dressing. The example at the far right would give the most uniform grind.

Originally long and narrow, the hopper now became in effect a large, rectangular, high-sided box with a grinding surface on its under side. We shall call this type the push mill, since most of the grinding was done as the operator pushed the rubber away from him. Even with its wooden crossbar handle, so large a stone was difficult to manipulate; so the meeting faces of the stones were often slanted away from the operator, and gravity aided the downward push. The stone was drawn back by swinging its sides alternately upward. By this time the push mill had become so large and heavy that few women could operate it, and so productive that only very large households would require one.

It occurred to someone that if he anchored one end of the handle of the push mill to a fixed pivot, he could use *both* his hands and arms on the other end, swinging the stone back and forth in an arc of a circle. This lever mill called for a decided change in the shape of the upper and lower stones; for restoring the grinding surfaces to a horizontal plane; and for raising the whole apparatus to waist height, on a table or base, so that the operator could stand upright and exert the whole strength of his body as he stepped forward and back with each long stroke of the heavy push bar (Figure 37). A much greater enlargement of the stones and lengthening of the grinding stroke was now possible, with a proportionate increase in yield which must have made the simple, old-fashioned saddlestone look like a mere feminine toy.

The lever mill was an industrial machine, out-size for domestic use, intentionally adapted to factories run by men for profit. These early enterprises were combination mill-bakeries, with bread as the commercial product. It is doubtful if flour was sold in substantial quantities in early times. Because grain keeps well, while flour is highly perishable except under controlled conditions which were not then understood, it was the universal custom in early times to grind grain only as flour was needed for immediate use. Thus grinding was a daily—and day-long—chore in the home. This practice was carried over into the early bakeries, and commercial milling made its appearance as the first operation in the manufacture of bread. The lever mill was the first device capable of the quantity output which such establishments needed to make them really profitable, financially and socially; and it is still in use, even today, in Greece—a fine example of the persistence of primitive tools. Requiring less skill and mental effort to use, and being cheaper to make, such tools are retained long after better appliances are available. The advanced devices themselves are apt to be superseded by further improvements, but workable elementary forms are seldom completely discarded.

In power applied, in its use of the lever principle, and in its mechanical uniformity of action, the lever mill stands far ahead of all other grinding devices we have described. Of course, we cannot be sure from the available evidence that the chronological order of invention was as neat as our account of it (Figure 38): in a period of active innovation and experiment, some of the logically more advanced forms may have appeared out of turn. More significant than the exact order of their invention, however, is the fact that these improvements appeared in the same general area within a comparatively short period of time. Most of the Delian forms, including even the lever mill, have been found in settings dating from before the middle of the first millennium B.C., with examples cropping up in widely scattered places. But it was among the Greeks that all of them made their appearance together and, in a period of less than one hundred years, underwent a rapid synthesis that set Western milling on the course of development it has followed ever since.

A spur toward further improvement lay in the fact that the lever mill

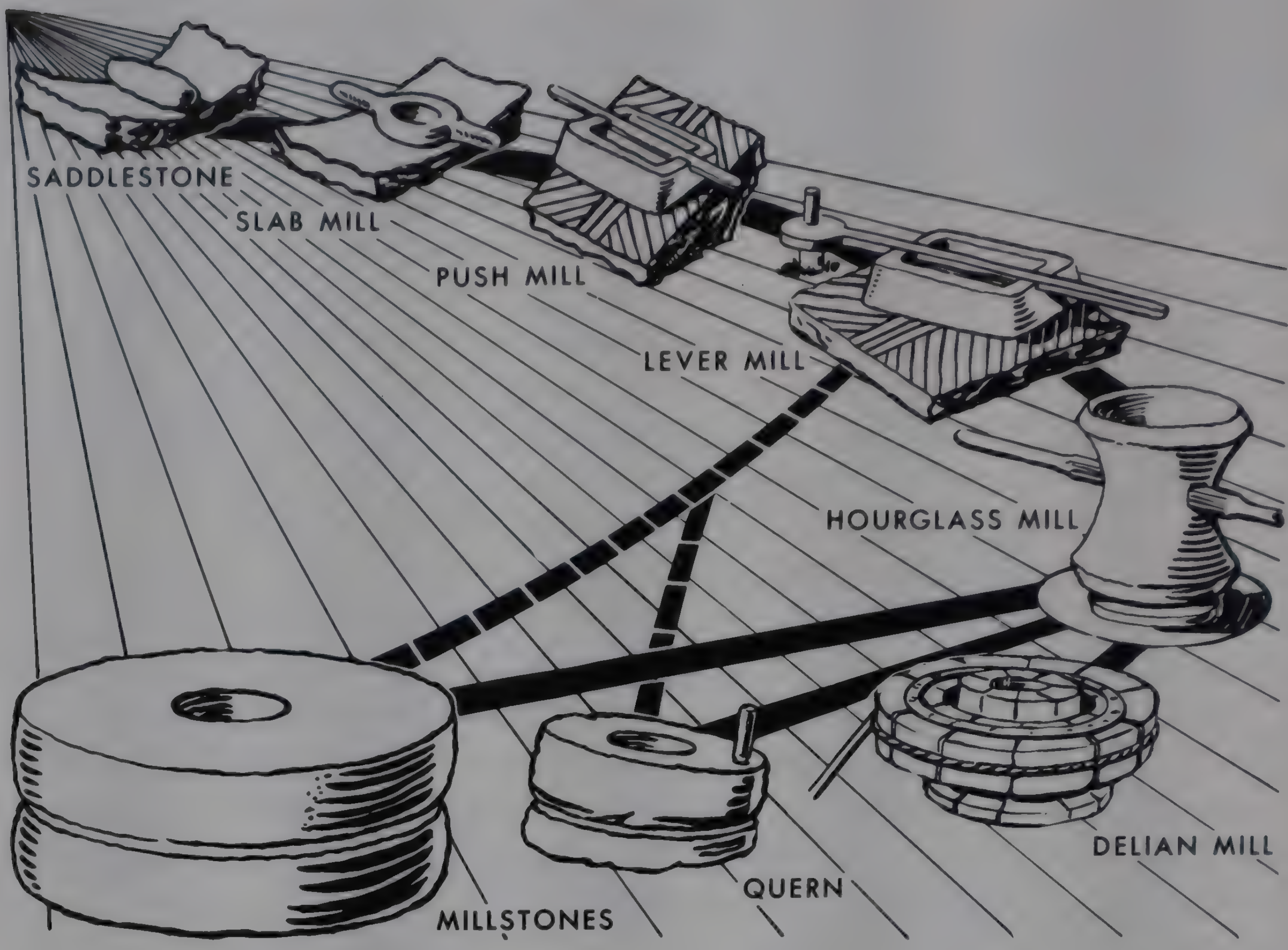


Figure 38. Possible lines of evolution from the saddlestone to the millstone. The great leap came when the arclike motion of the lever mill gave rise to a mill using full rotary motion. In Greek areas, the hourglass mill apparently preceded the quern; farther east the quern was reached by a single step, made before 700 B.C. The hand-powered quern preceded the water-powered millstone by at least three hundred years in the Mediterranean area; farther east they may have come closer together.

had grave deficiencies. There was no provision for automatic removal of the grist, which would accumulate between the stones or be pushed out just beyond the field of movement of the upper stone. Also, since the dead weight of the upper stone rested directly on the lower, there was no way of regulating the degree of fineness, and the bran was ground equally with the endosperm. Most important of all, there was a waste of effort since the motion was still reciprocal instead of continuous, and it could be managed only by a human being.

From the saddlestone to the lever mill we can follow a step-by-step sequence of development, and the arc of the lever mill's movement undoubtedly suggested the full circle of a rotary mill. Between a completely rotary mill and anything that had gone before there is an intellectual leap of startling abruptness. We are in the presence, here, of positive invention at its creative best. As Curwen has said, "Such an advance could only have been the product of a brilliant engineer or mathematician – some forgotten forerunner of Archimedes who failed to achieve the immortality of the classics."

The available evidence indicates, however, that as often happens in the case of critical inventions, the problem was solved more than once and in different ways, with varying degrees of success. One remarkable and very early example (Figure 39) occurred far to the east and anticipated the flat, circular millstones of much later times. Because of its remote origin – in Urartu, among the little-known Khaldis dwelling around Lake Van in eastern Anatolia – it appears to stand entirely outside the line of Western milling development.

Only one example of the Lake Van type has so far been described in print. It cannot be later than the eighth century B.C., since Urartu was conquered then by that same Shalmaneser III of Assyria whose bronzes we have already reproduced (Figure 32). It is a fine example of an upper stone for a quern, as the manually rotated circular millstones were later called, lacking nothing for completeness except a dressed grinding surface. The marks of the device, later called a rynd, which supported it over its base are visible on the under surface, and suggest that the stone may have rested on the top end of an axle passing through a hole in the lower stone. This would have provided a crude means of regulating the fineness of the grind, anticipating the much later arrangement shown in Figure 48. The small holes for handles in the side of the hopper indicate that it was turned

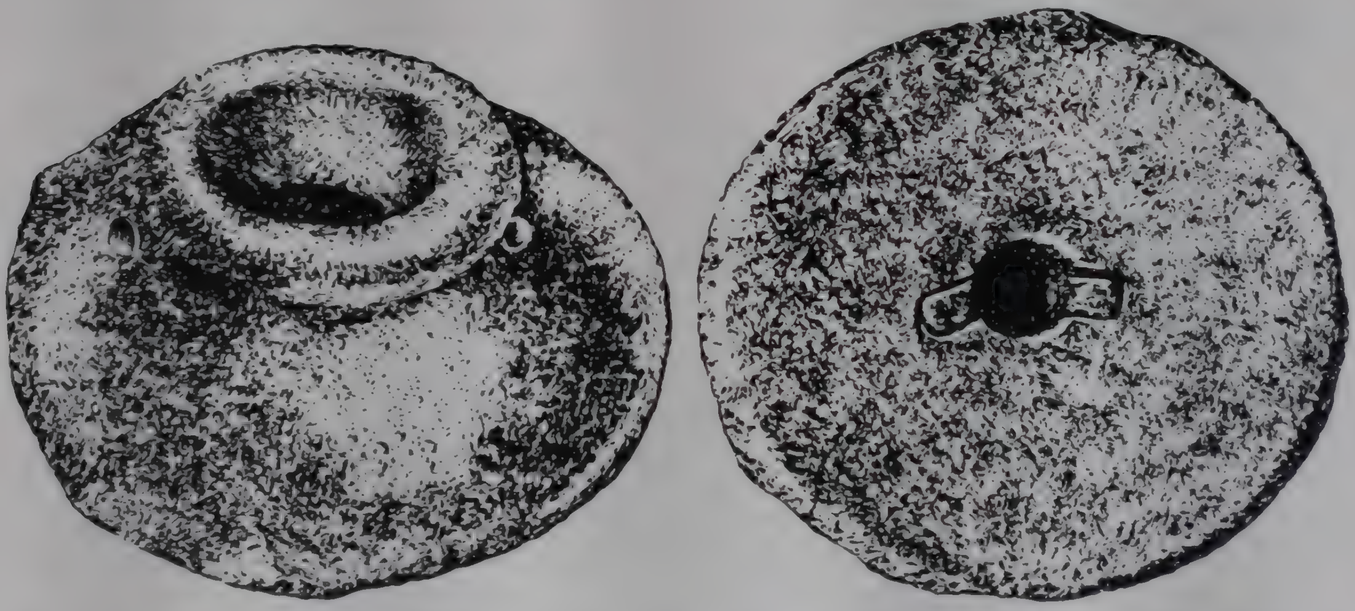


Figure 39. Upper quern stone, from Varaga in the Khaldi state of Urartu, in the Lake Van region of eastern Anatolia, dating from about the eighth century B.C. This is the earliest quern of which we have definite cognizance, and is complete with not only hopper but rynd. Tseretheli, the Russian archeologist who described it, is of the opinion that it was from a water mill, which mills were of very early date along King Menuas's canal in this region; but its small size – about 16 inches in diameter – and the three holes around the rim of the hopper, for the insertion of turning levers, make this view untenable.

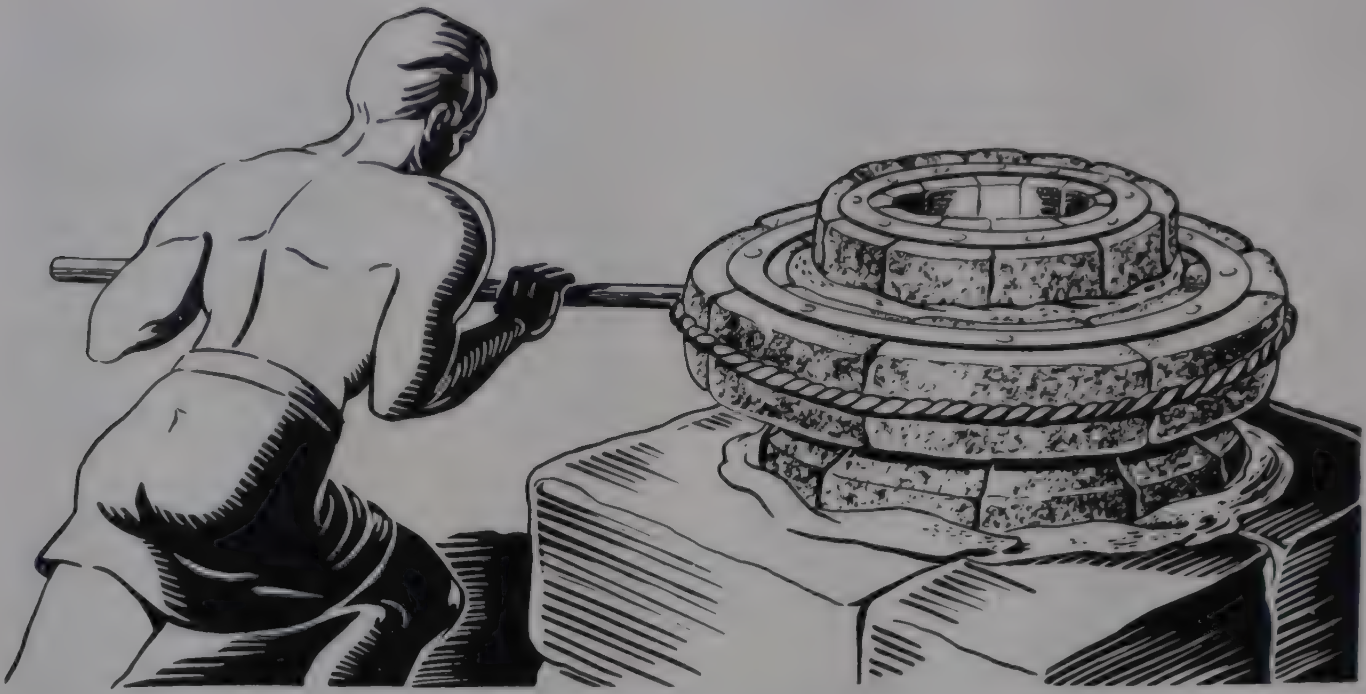


Figure 40. Delian mill, made of bound-together blocks of lava. This mill is without a true hopper, although there is a slight space at the top, between the stone rings. The outer ring rests directly on the inner ring. This mill may be an adaptation of the hourglass mill, or transitional to it.

manually. For technical perfection no less than for early date and out-of-the-way location, this quern stone is most remarkable.

Various other adaptations of rotary motion were made without effect on the later progress of milling, in these instances because of inefficiency. One such abortive device found at Delos, and apparently abandoned in favor of the more efficient hourglass type, is shown in Figure 40. This Delian mill was without a true hopper and without means of suspending the upper stone over the lower. Still another approach to rotary grinding is the edge runner, of early origin and used occasionally for grain grinding, but better adapted to crushing ores and other heavy materials (Figure 41). Because of its use for these purposes in South America, it is often called the Chile mill.

The first adaptation of rotary motion to milling, sufficiently successful to launch a permanent trend, was a Greek invention. The critical problem in a rotary mill was to keep the grinding surfaces in virtually parallel planes. The Greek solution of this problem was to fit the two stones together as a mated pair of cones, which would be self-centering (Figure 42). In addition the upper stone was enlarged above its waist into a second conical hollow about as big as the lower grinding compartment, making a hopper for continuous feed and giving the mill its hourglass shape. This upper stone could then be rotated steadily by man or beast, pushing or pulling the wooden crossbars. Since the upper stone was supported above the lower stone by the rynd, a grinding space between the two was provided. The big hopper could easily be refilled by a helper without pause in the

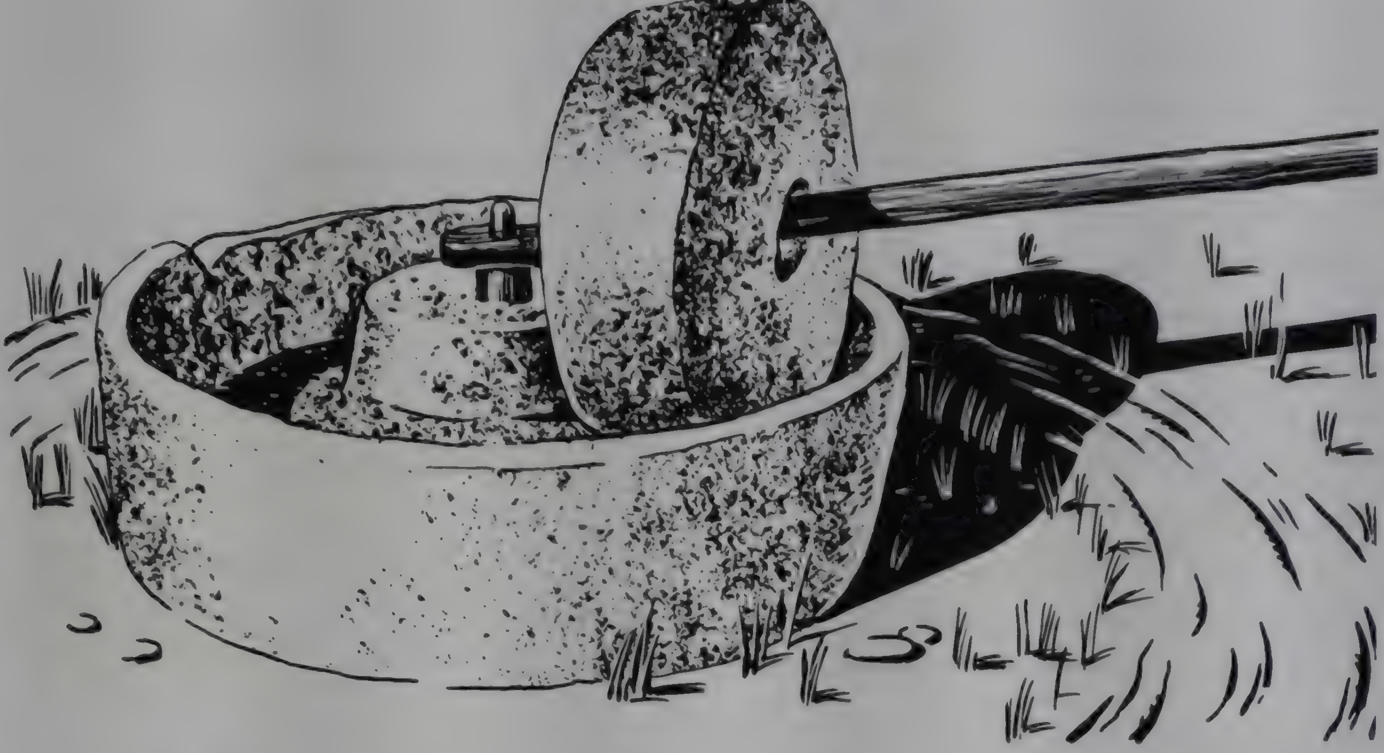


Figure 41. Chile mill, or edge runner, used sometimes for milling, but more likely to crush than grind the grain. It is more commonly used for crushing ore.

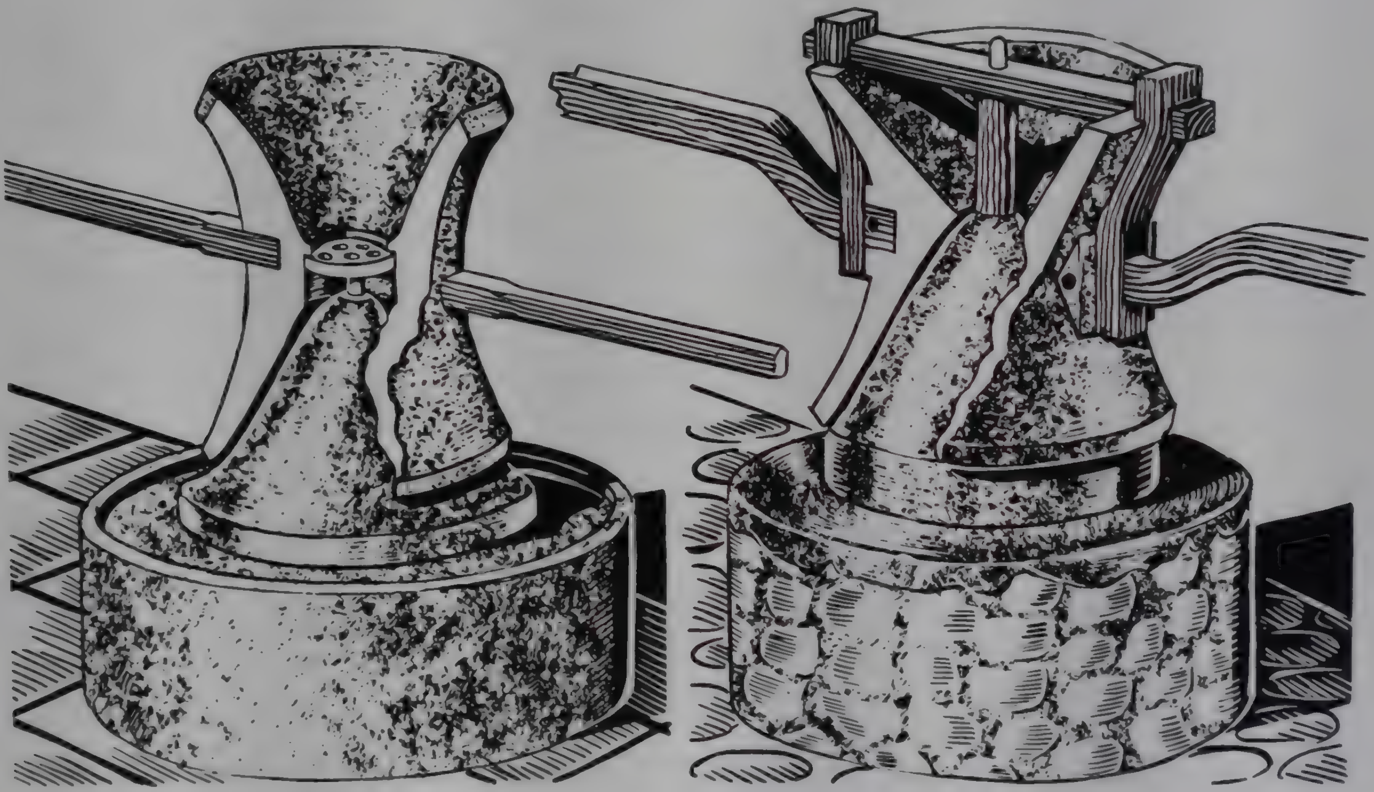


Figure 42. Hourglass mills, shown in cutaway view to indicate alternative methods of mounting the *catillus* on the *meta*. The method of connecting the stones shown at the left is the better of the two, and was later applied to querns and to millstones, when the metal device became known as the *rynd*. Hourglass mills have been found at various places in the Greek world, including the Island of Delos, and at Pompeii and numerous other locations in the Roman west.

grinding, and the grist was delivered into a trough around the base of the lower stone. These innovations developed into features of all later milling practices.

The hourglass mill had certain shortcomings, aside from its innate clumsiness: control of the space between its two stones was crude and inaccurate, and the rate at which grain was fed into it could not be regulated accurately. Still, its virtues so far overbalanced its faults that it continued in use in the Greek and Roman world for several centuries on both sides of the beginning of the Christian era. It often stood side by side with lever mills, which may have been used for the first rough grinding, as mortars were used elsewhere.

To the Romans, rotary mills were *mola versatilis*, in contrast to *mola trusatilis*, or thrusting mill, which we have called the lever mill. The upper stone of the hourglass mill was called the *catillus*, or bowl, the lower stone the *meta*, named by shape analogy after the conical stones used to mark distances on race courses. But in Greece the upper stone was called the *onos*, or donkey, from at least the fifth century B.C. if not earlier, a clear indication of the promptness with which animal power was utilized once the rotary principle had been adopted. This marks the first known use of animal power in milling; the first use, in fact, of nonhuman power of any kind except for those devices we have cited, more ingenious than capable of further development, which helped operate heavy pestles in mortar pounding.

Human power, slaves for the most part, continued to be used, and the lot of both humans and animals was anything but a happy one. In Apuleius' *The Golden Ass*, dating from the first part of the second century A.D., the hero was turned into a donkey by a magic potion and sold to a bakery. He thus describes the poor unfortunates of the mill, from which we can well understand why millers were in such bad repute among Greek and Roman writers: "Good Lord, what broken down men were the lot I saw there! Their backs and shoulders, which were protected only by ragged cloaks, were cut and seamed by blows from the whip. Their heads were half shaved, and their brows branded, to prevent escape. Their ankles were fettered in heavy chains. They were covered with a conglomeration of meal and ashes, just as athletes are with the dust of the circus."

In spite of the long and widespread popularity of the hourglass mill for industrial milling, by far the greater part of all bread grains continued to be ground in the home for two thousand years after industrial milling began. For domestic use the hourglass mill was too large, too expensive, and too difficult to operate. But the advantages of continuous circular motion, with the grain fed downward between the stones from an ample hopper above, led to the adaptation of these principles to a more modest home appliance. Abandoning the hourglass form with its necessarily massive proportions, two circular stones of manageable size were fitted to each other with a slight conical rise toward the center of the two grinding surfaces, slippage being prevented by a central pivot. The hopper and rynd in the upper stone were retained, and a crank handle in the latter made it possible for a woman to turn it without immoderate exertion.

The many superiorities of the quern, as it was called later in its history, caused it to supersede the saddlestone for home milling among all but the most isolated and backward peoples. The slab mill, the push mill, the lever mill, and the hourglass mill all were transitional forms and passed out of general use after classical times. But the quern was so much more efficient than any hand mill hitherto devised, and so well adapted to small-scale, family production, that it continued in use as long as grain was ground in the home and still serves to supply domestic needs in some more static parts of the world. It has even greater historical interest as the direct ancestor of the circular millstones used in water and windmills.

The quern was in use in many parts of the Mediterranean world by the fifth century B.C., and only a little later it had spread to the Celtic tribes of Gaul and Spain. Pliny says that it was invented by the Volsinians, members of the pre-Roman Etruscan federation, but Pliny's historical accuracy is often questionable. He of course could have no knowledge of its exceedingly early use near Lake Van. It is more than possible that a device so

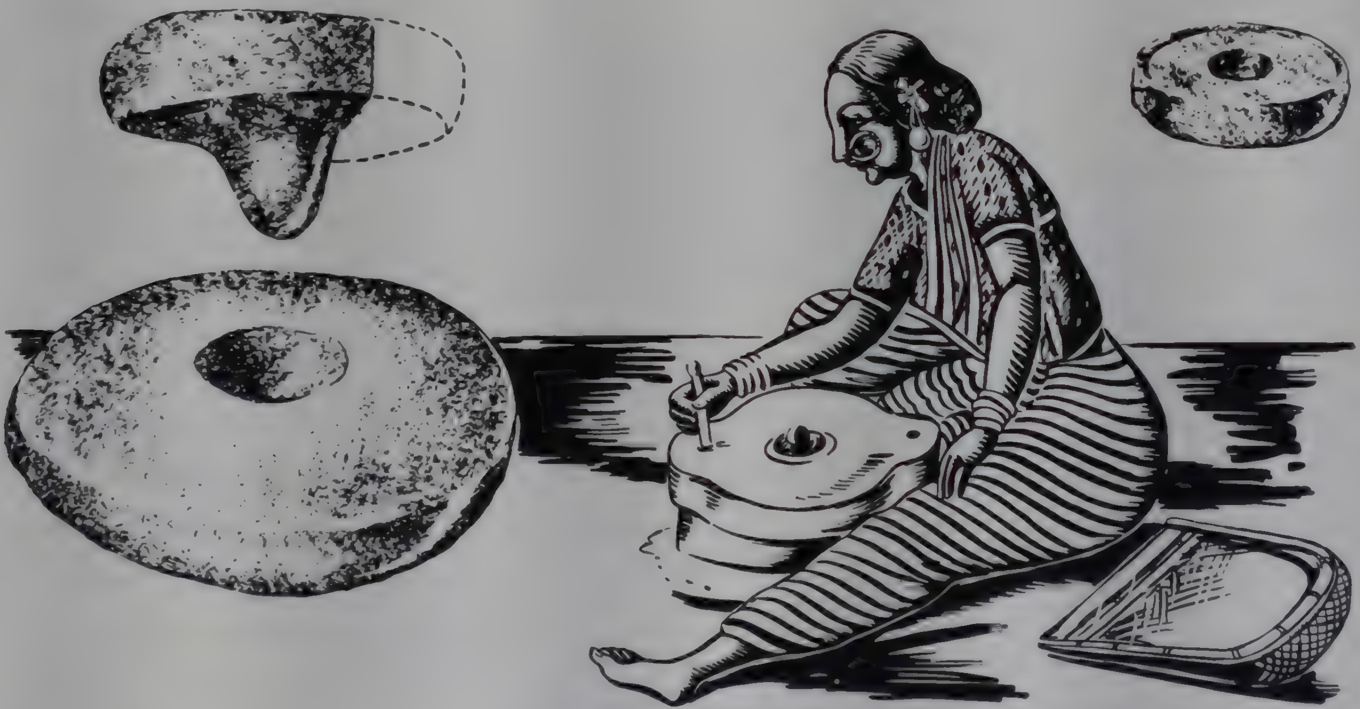


Figure 43. Early Palestinian and Hindu querns. At the left, a grain quern from Gezer, with a maximum diameter of about 10 inches, dating from a century or so B.C., which may have been derived from considerably earlier small "paint grinders" similar to the one at the upper right. These stones had no crank for turning, and may have been worked back and forth in a half-circle. In the center, a Hindu woman using a crank-rotated quern of about the same age as the Palestinian grain implement.

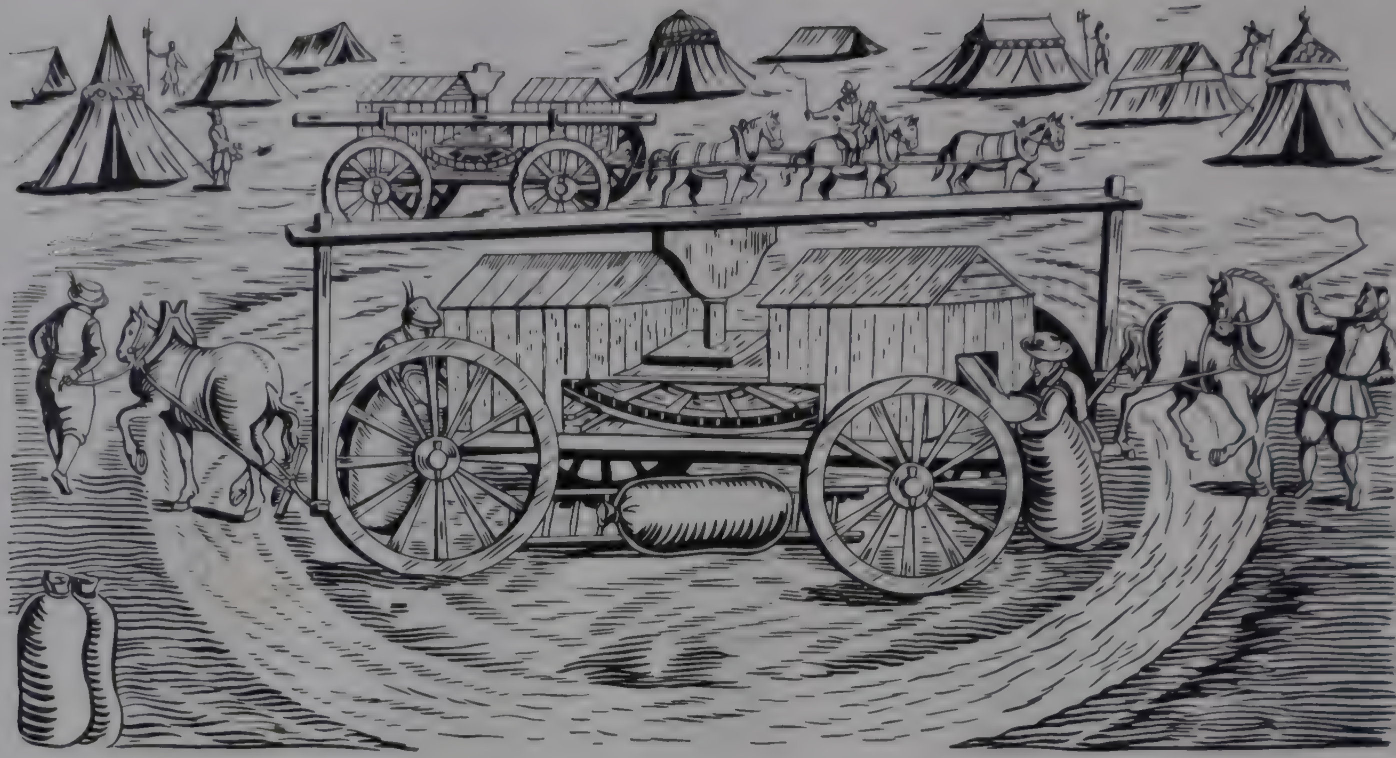


Figure 44. Seventeenth-century military querns, driven by horsepower. From Zonca, *Novo Teatro di Machine et Edificii* (Padua, 1607).

efficient was invented more than once, in widely separated areas, as soon as the principle of rotary motion had been mastered; Figure 43, for example, shows rotary mills from Palestine and India which may not have had a common ancestor.

As we have seen in our day, military urgencies are often a more powerful spur to technical and scientific progress than the milder pressure of civilian needs, and in classical times there existed the modern necessity of feeding large armies on the march and fleets at sea. At that time neither troops nor ships could carry a supply of perishable flour — they must carry grain and grind it to meet their daily needs. In military camps and on shipboard the size and weight of the hourglass mill or even the lever mill would have been burdensome, and the need for a lighter, efficient mill hastened the development and spread of the quern. Xenophon in his *Cyropaedia* remarks on an army's need for hand-milling equipment. By the second century B.C., if not earlier, the Roman army was equipped with querns, in the ratio of one to every squad of five to ten men. Thus no place where the far-flung legions penetrated would have remained in ignorance of the device. In modern times querns worked by horsepower were used to grind meal for armies on the march (Figure 44).

One of the quern's fundamental improvements was the greater ease with which the upper stone could be suspended over the lower in such a way that they were in actual contact only near their outer edges, and the greater ease with which this relationship could be adjusted as the grinding surfaces became worn. One method of suspension in early use by the Celts in Gaul is shown in Figure 45; eventually a perforated metal rynd like that used in hourglass mills provided a fairly efficient method of regulation by adjustment of the pivot height – a much easier procedure in the quern than in the cumbersome hourglass mill.

The hopper of a quern in some cases was merely an enlargement of the opening (the eye or bosom) of the upper stone, in some cases an additional container placed above it (Figure 48). The grinding surfaces usually were striated or dressed, and as the grain moved outward toward the circumference it was rubbed and cut more finely. The action was improved if the grain was dried or even slightly roasted, to be made more brittle. And there was a knack in feeding a proper supply of grain between the stones: with too little the outer edges of the stones ground against each other, introducing sandy grit into the meal; with too much the meal was coarse.

By these refinements, which were introduced with more or less success into domestic milling with the quern and into industrialized milling with the hourglass mill, the quality of the grind was greatly improved and the quantity increased. The improvement in quality is shown by the growth of interest in sieving in Rome, and by the appearance there of various grades of flour. More care also was taken with the stones themselves, the Romans preferring stone from Andernach on the Rhine, which continued as a source of supply for millstones into modern times. These Andernach

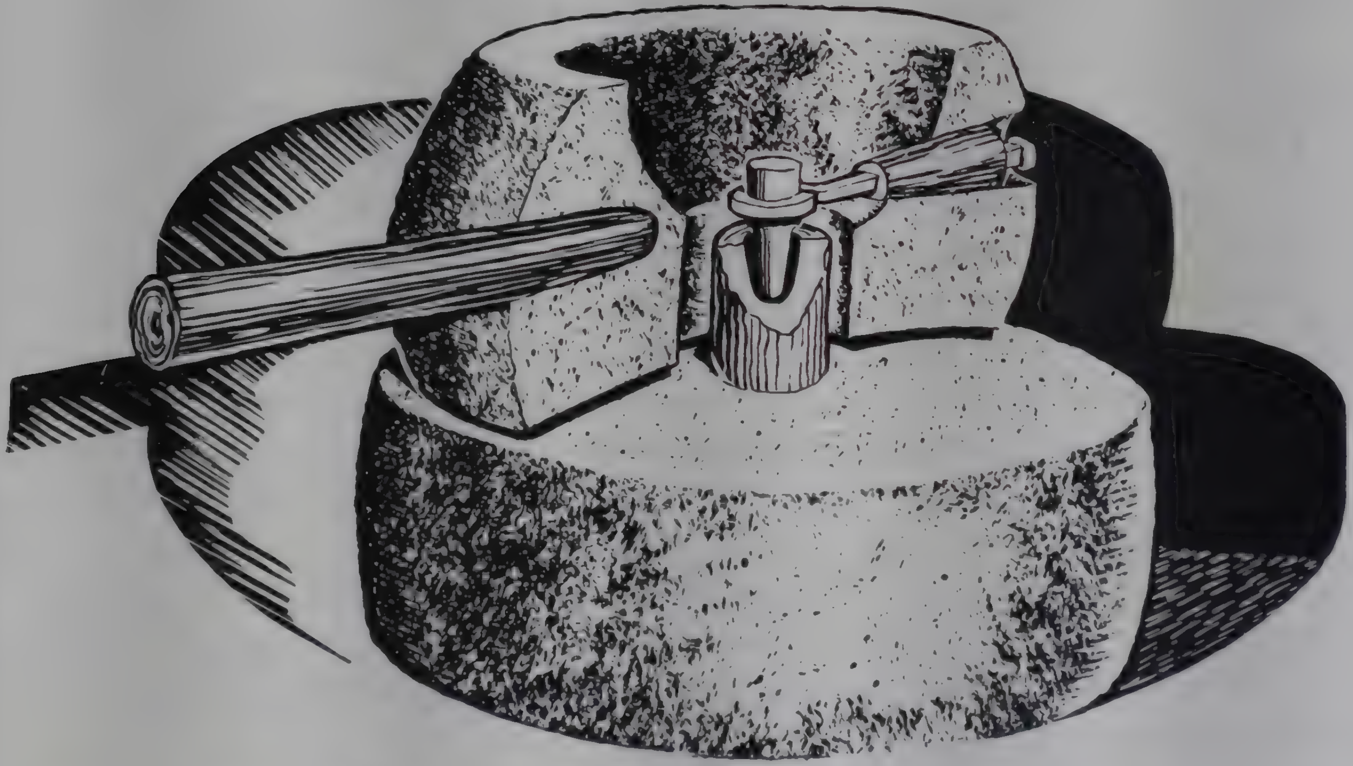


Figure 45. Pre-Roman Celtic mill from the Auvergne, France, shown in cutaway view to display the unusual method of mounting. About 150 querns were discovered at a single location, all of this type. Note the slanting mating surface between the two stones; also the horizontally extended handle, which would have made rotation difficult.

stones were unusually hard and can be identified by their crystalline content.

The quantitative increase obtained with querns was marked. In Homer, the palaces have up to fifty girl servants, whose hardest task is operating the saddlestones. They often work through the night, "their knees broken with weariness." Werne says of saddlestone grinding in the Sudan that "a slave can only make meal sufficient for one day's consumption for eight persons, if she works from morning to evening; and this quantity is taken for the standard for a day's work." In eighteenth-century quern grinding, using an implement probably inferior, if anything, to the best Roman examples, eight hours' labor would grind a bushel of wheat. It is probable, therefore, that the quern was at least twelve times as productive as the saddlestone.

We can be certain that industrialized milling in classical times was even more productive. The hourglass mill required more effort per unit of grinding area than the quern, but power was available and cheap, so this made little difference. What did count was the fact that these machines had a considerably greater grinding area, and with their large hoppers could be operated more continuously. They were perhaps three times as productive as the quern, per unit of time, and enormously more productive than all previous milling implements. But because of the difficulty of regulating the stones, the quality of the grind cannot have been uniform; it must have been markedly inferior to that obtained with good quern grinding, though better than the grist from good saddlestone grinding.

It was the high output of the hourglass mills which made them the mainstay of industrialized milling. Pliny tells us that public milling was not introduced into Rome from Greece until 168 B.C., but in early days Rome was notoriously slow in taking up newfangled notions. Roman millers, like the Greek millers before them, were called pounders, their name, *pistores*, being related not only to our *pestle* but to the Greek *ptisso*, "pound," whose root, *ptis*, refers to barley—the name thus indicating not only the method of reduction used at first, but the grain upon which it was employed. It is a strange fact that Pliny, in spite of his encyclopedic curiosity, makes only a single reference to the quern, and in all other places suggests that grain was reduced by pounding; he mentions even a pestle worked by water power. The saddlestone is never described, nor does Pliny refer to the water mill with millstones, although he lived until A.D. 79, a century after such a mill had been carefully described by the Roman architect Vitruvius.

About twenty public bakeries with their mills and ovens have been uncovered at Pompeii, preserved by the eruption of Mount Vesuvius in A.D. 79. This town had about one mill-bakery for every thousand inhabitants, whereas the ratio for Rome was about one for every two thousand.

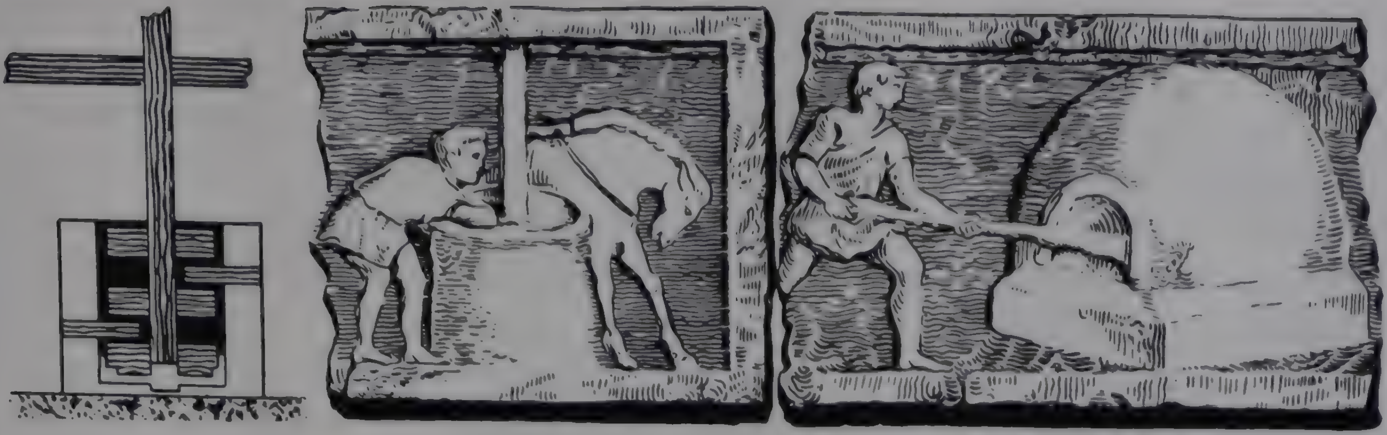


Figure 46. Scenes from the tomb of M. Vergilius Eurysaces, a former slave who became an important miller-baker, now located at the Porta Maggiore, Rome. At the left, a kneading machine. At the right, an oven from which a man is taking bread on a long-handled paddle.

We know of one later Roman establishment, that of the Latini brothers, which processed and baked 1,000 bushels of flour daily, or between 100,000 and 150,000 Roman loaves, which would be a mass-production enterprise even by today's standards; over 500 cwt. of flour was produced daily.

The ovens of Pompeii show that no fundamental improvement of the hourglass mill was needed at the time. These ovens were small, and heated in the primitive manner by building a fire in the baking space and raking it out before the loaves were put in (Figure 46). A new fire was necessary for each batch, even though some of the ovens had a flue arrangement that made good use of the heat. Larger and better ovens would have to be designed before there would be much need for the increased grinding capacity of the water mill, which had been invented long before the destruction of Pompeii.

Grain for the mills of ancient Greece, even in Athens of the fourth century B.C., was grown by very primitive methods: the procedures recommended then by Xenophon and Theophrastos differ but little from those laid down early in the eighth century B.C. by Hesiod in his *Works and Days*. Almost identical methods were in fact followed everywhere in the ancient world, except under the unusual conditions of Mesopotamia and Egypt, until Carthage and Rome initiated numerous improvements. The system was designed for a region of relatively light rainfall, concentrated in the winter months. Fields usually lay fallow in alternate years, but were plowed at least three and often four separate times prior to the next year's sowing — in September, at midwinter, in the spring, and at midsummer. This practice was so old that even the field shown on the shield of Achilles in the *Iliad* is spoken of as "thrice-plowed." Pliny tells us that the Etruscans sometimes plowed up to nine times. Finally, in early November, "at the setting of the Pleiades," the fields were sown with winter grain in the course of a last plowing, the seeds being covered with the hoe. Comparatively little spring-sown grain was grown, especially in Greece. The crop was harvested in the following April.

This system was more suited to the light *ard* plow with its shallow scraping of the earth (Figure 12), its plodding oxen and reluctant slave plowmen, than it was to the heavy, horse-drawn, deep-biting moldboard plow managed by free men. And among free men it was a system better adapted to the patient, thorough Romans than to the more mercurial Greeks. The modern type of plow appeared farther to the north, where there were heavier, more rain-drenched soils and where work was done under a different labor system.

The Romans improved considerably on the original Mediterranean agricultural methods. They kept cattle and manured their fields, used compost heaps and plowed under "green manure," practiced crop rotation and seed selection, and they excelled in carefulness and attention to detail, then as now the secret of success in farming. But neither Greece nor Rome was grain-sufficient in ancient times. It has been estimated that at least three quarters of the grain needed by Athens in her prosperous days had to be imported, and the principal grain food of ordinary Athenians was barley, because of its cheapness rather than from preference. But considerable emmer was consumed, some durum, and even some bread wheat in the form of *compactum* and *vulgare*.

In ancient Italy the need for importing grain was aggravated not only by the growth of Rome and the greater adaptability of the land to the olive and vine, but also by the Punic Wars with Carthage and by the trend toward *latifundia*, or large estates. Early in the third century B.C. we begin to hear of large farms in Italy, and these grew into great plantations managed by responsible slaves and run solely for profit by absentee landlords, on the Carthaginian pattern. The ravages and neglect caused by long wars accelerated the growth of these great estates. For the landlords, cattle-raising and crops other than grain were more profitable: Cato, who died in 149 B.C., listed grain as only sixth in value among Italian crops. Yields fell off from about 26 bushels an acre near the middle of the first century B.C. to below 8 bushels one hundred years later, probably because the best land was put to other uses.

As Italian cereal production precipitously declined, Rome became increasingly dependent on grain imports from territories annexed across the seas—first Sicily, then Spain; and after the destruction of Carthage in 146 B.C. North Africa, now arid, became Rome's great granary under a vast extension of the *latifundia* there. As they were conquered, Gaul, Britain, and particularly Egypt sent tribute of grain to Rome, a great flood of importation by sea in spite of Rome's exceedingly poor harbors.

We can be sure that the Romans imported all the varieties of grain available in satellite regions, including even the humble einkorn. As Jasny has shown, these were numerous; but economic and climatic factors nevertheless limited the common range of consumption. Pliny in the first century A.D. tells us that acorns still constituted the wealth of many nations, barley or emmer *puls* (porridge) was still the mainstay of the Roman populace, and there were few who could afford the superior varieties of wheat. Ordinary Romans ate little meat: Caesar tells us that his soldiers on one occasion managed to endure meat when the customary grain was lacking.

Throughout ancient times the wheat commonly eaten in Rome belonged primarily to the two-genom, or emmer, family. At first it was emmer itself with its hulls (*far*, the ancient *adorea*, often mistranslated *spelt*); throughout Roman history the most solemn form of marriage (*confarreatio*) was made binding when the couple sacramentally consumed a cake of *far*—the origin of our wedding cake. Increasingly, as time passed, emmer was displaced by durum and to a slight extent by *turgidum*, naked members of the same group, which the Romans collectively called *triticum* (wheat). For their better flour, the Romans used three-genom wheats—*vulgare* or *compactum*—collectively called *siligo*, which cost perhaps 20 per cent more than other wheats and produced *similago*, fine flour, which Pliny described as coming from "the very choicest of all the varieties of wheat. It is white, destitute of all flavor, and not oppressive to the stomach." It is possible that Rome's *siligo* was grown mainly in the Po Valley or even across the Alps, for the Mediterranean climate is not well adapted to the bread wheats. Pliny, however, praises especially the wheats of Etruria, the district lying immediately north of Rome.

It will be noted that the Romans had practically the same wheats as the Greeks, though they came in part from different regions, and that durum especially, and even the bread wheats, figured more largely in their diet than with the Greeks, while barley in time came to take a much less prominent place. The Romans were familiar with many more wheats than the early Egyptians. The difference is shown by the fact that emmer was used for bread in Egypt, whereas it made porridge for the most part in Rome. It was in Rome that fully leavened breads first began to displace earlier quick breads and that wheat first outstripped barley in human consumption.

Pliny describes a number of leavens, including dough left to ferment from the previous day's mix, as well as cakes made of wheat bran and the fermenting barm of wine. But the superiority of Roman breads was not due to leavens, but to the wheats used and to the greater attention given to sieving. For most of their breads the Romans used durum and *turgidum*. We must not exaggerate their excellence, for, as we have already pointed out, ordinary Roman bread was so heavy that it sank in water. But the best Roman breads were made from *compactum* and *vulgare*, and even the former is superior for the purpose to the other wheats that were available.

These flours were carefully sieved – just how we do not know, although we are told that one grade of fine flour and two of meal were produced, besides the bran. The chapter in which Pliny discusses this question is a mathematical puzzle which can be interpreted as stating that Roman millers achieved 75 per cent extraction for the three flour grades, 25 per cent of the grind being bran – a result quite comparable to present-day results. But only one quarter of the total grind was fine flour, whereas modern millers are accustomed to obtaining over three times as much. The higher class of Romans laid great emphasis on the whiteness of their flour. In discussing *alica*, a special flour made from emmer, Pliny notes "a most singular fact – chalk is mixed with the meal, which upon becoming well incorporated with it, adds very materially to both the whiteness and the shortness [*teneritatem*] of the mixture."

Bread in our sense of the term was a Roman creation. And it happens that we have some of their actual loaves and pastry, reasonably well preserved, from the ruins of Pompeii. The loaves are round and stand about two inches high, just as they are shown on the Pompeian wall painting reproduced in Figure 47. They look more like large rolls than like modern loaves, but were far different from the pudding breads and quick breads of the early Egyptians.

It also happens that the reliefs on a sarcophagus in Rome near the Porta Maggiore give a very complete conspectus of the craft. This was the tomb of M. Vergilius Eurysaces, a slave who, having gained his freedom and prospered as a miller-baker, had his tomb constructed out of old stone mixing troughs. The reliefs depict grain-buying, grinding the grain with an hourglass mill, sifting the grist, selling flour, mixing the dough with a donkey-driven mixer, kneading it by hand, baking, weighing the loaves, and carrying them away (Figure 46 and Oval, Chapter VII).

As Rome increased her territory and multiplied her provinces and slaves, it seemed advisable first to amuse, and before long to feed, the idle city proletariat; and so the state adopted the policy *panem et circenses* – the "bread and circuses" whereby the mob was appeased. The food dole was first set up in 123 B.C., as a system whereby the government sold a full ration of grain monthly to every adult citizen at about half the prevailing price. From this time on, grain for the people was a political football, although it was not until 58 B.C. that free grain was first regularly distributed. It took 20 per cent of the entire revenue of the state to support this dole, and an additional 10 per cent or more was spent over a period of five years in an effort to keep the price of grain down for those who purchased it. In 46 B.C. Julius Caesar found that 320,000 Romans were receiving free grain, out of a total free population of perhaps 600,000. By sending colonists from the city to the provinces at state expense, he managed to reduce this number to 150,000; and it was further reduced later,

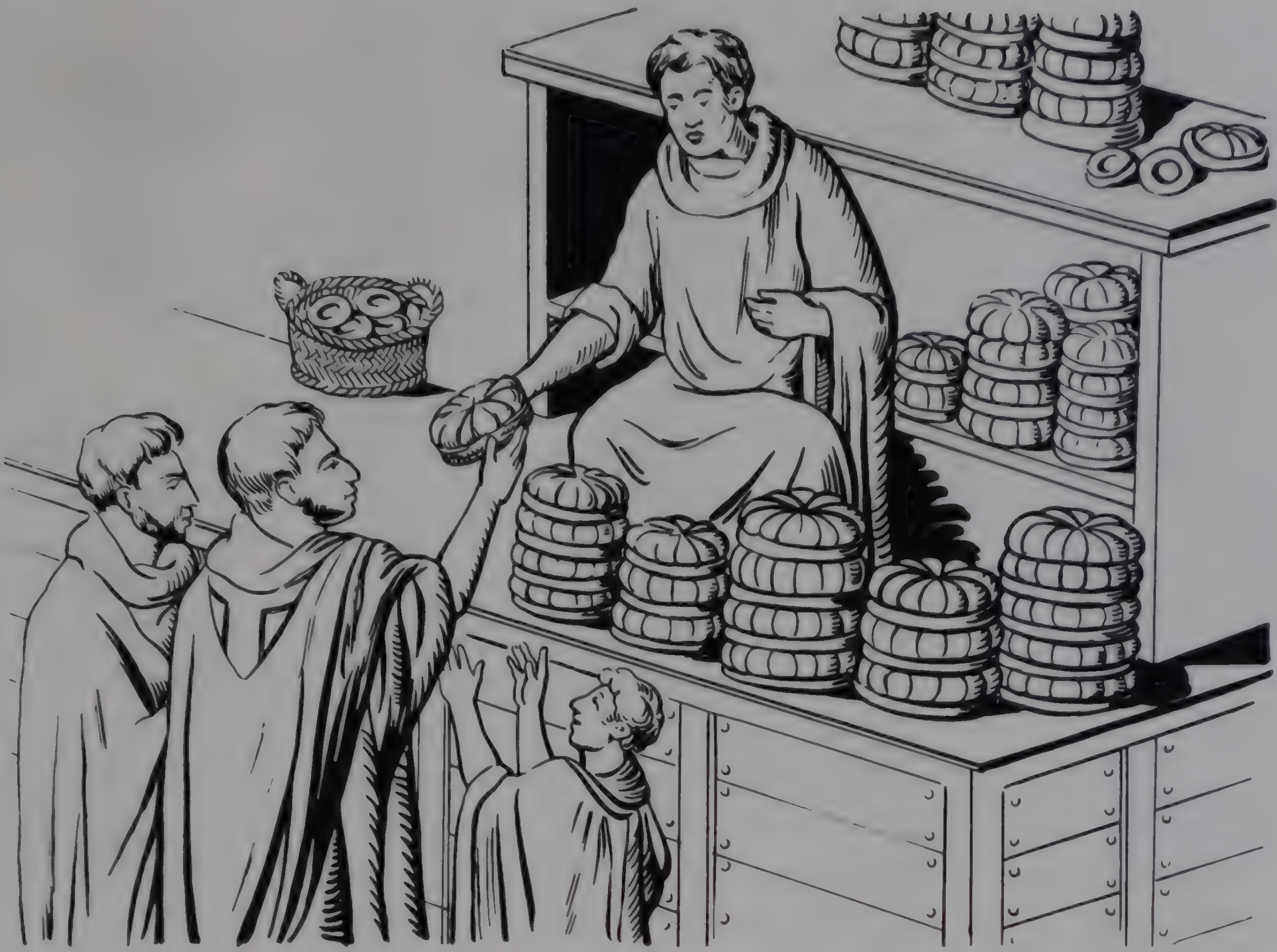


Figure 47. Pompeian wall painting showing the common Roman flattish, divided loaf; also, in the basket, another variety of bread or pastry very similar in shape to our pastry shells.

so that by the early third century A.D. only 75,000 were on the dole. Finally, however, in the fourth century, the distribution was made in bread, so that practically the entire milling-baking trade was working for the state. Thus one of the principal Roman industries was nationalized, and the populace no longer needed even to grind its grain or bake its bread.

This caused little change in the status of millers, however, for already under Trajan in the early years of the second century A.D. they had been organized into a "College of Pistors" which bound them to their work and established their duties and privileges. For them, as for other artisan groups, a system of industrial serfdom was slowly grafted onto the slavery system as the latter decayed. In these late days, also, with the Roman Empire tottering to its end, the water mill had all but superseded the old system of milling by slave and animal power.

The great growth of industrialized milling in the Roman world was confined to the cities, and its perishable products were not distributed over any wide area. Throughout rural regions and even to some extent within the cities, domestic milling continued to be practiced. This was not only for reasons of necessity or economy, but often by choice: good home-baked bread made from superior flour ground skillfully on the quern at

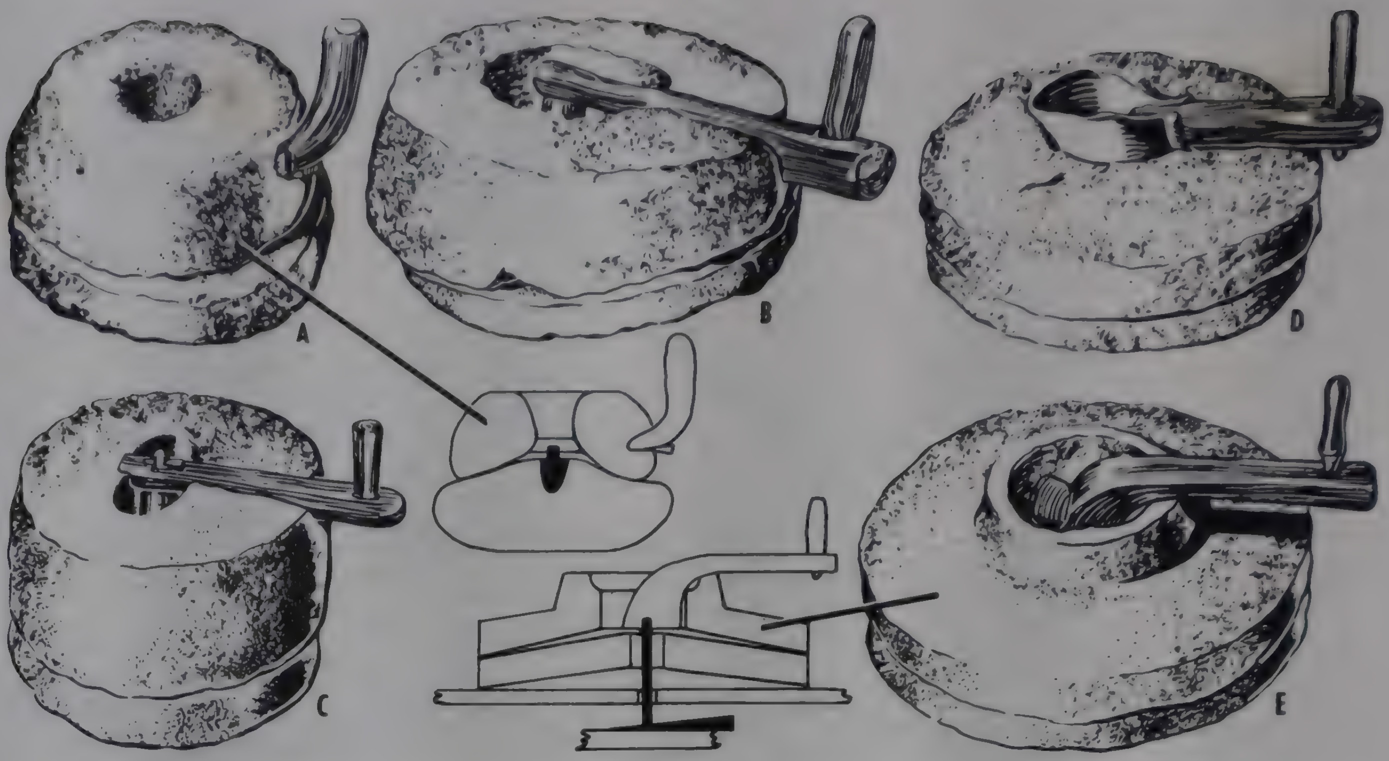


Figure 48. Early British querns. A, pre-Roman Wessex type; note method of mounting upper stone by means of a peg. B, pre-Roman, from the Trundle, Sussex, from before 50 B.C. C, probably from Iver, first century A.D. D, from Hassocks, Sussex (second century A.D.); note separate hopper. E, from Thundersbarrow Hill, Sussex (fourth century A.D.); note device for tentering the upper stone.

home undoubtedly was preferred in many households which could obtain the bakers' product. Wherever the Roman legions marched, they carried the quern with them, and often found that it had preceded them. Its use outlasted the Roman Empire itself, and surviving the competition of water mills and windmills it persisted through the Middle Ages and into modern times.

In Britain, the earliest Celtic querns, dating from the third century B.C., are small and have conical grinding surfaces, the upper stone merely being centered on a peg (Figure 48). We can be sure that they were rotated slowly, since the grinding surfaces are almost, if not actually, in contact. Gravity was relied on to carry the rather heavily ground meal out of these slant-faced implements. At the beginning saddlestones outnumbered querns ten to one; by the first century B.C. querns were more numerous by two to one. With the coming of the Romans in 55 B.C. the stones became thinner and increased in diameter, until some of them were mere discs, but better balanced and supported. The spindle which supported the upper stone sometimes passed all the way through the lower stone, and was held in place by a lever underneath, which could easily be adjusted or "tentered" to change the grind (Figure 48). These later querns were more rapidly rotated than the earlier ones, centrifugal force instead of gravity being relied upon to carry the grind from the center to the circumference and out of the machine.

The larger Roman querns were probably operated by men. In medieval times the querns again became smaller, and were almost invariably worked by women, except, of course, in monasteries. One new type was developed —the pot quern, shown in Figure 49, in which the lower stone was pan-shaped; grinding took place between the flat faces of the stones, exactly as in regular querns, and there was a spout in the side of the lower stone to assist removal of the meal. As the figure also shows, medieval querns, like querns from our southern mountains, were sometimes turned by means of a bar crank, reducing the labor of turning.

In the Middle Ages, the lords of estates in many parts of Europe attempted to monopolize a profitable trade by means of the "right" or privilege of *soke*, which was the exclusive franchise to grind grain for those living on their lands. Many of these monopolies were in the hands of religious organizations, and in England all granted before 1316 were supposed to pay a tenth of their profits to the Church. Mills were usually rented out by the lord to a miller, who was required to grind for a fixed toll paid in grain, usually one sixteenth, whatever the market price. Tenants who refused their custom to the lord's mill and attempted to grind at home or elsewhere forfeited their grain and were subjected to other penalties. This did not prevent them from doing bootleg grinding, however, or from selling to outsiders on occasion. As Ashley observes, "it may be

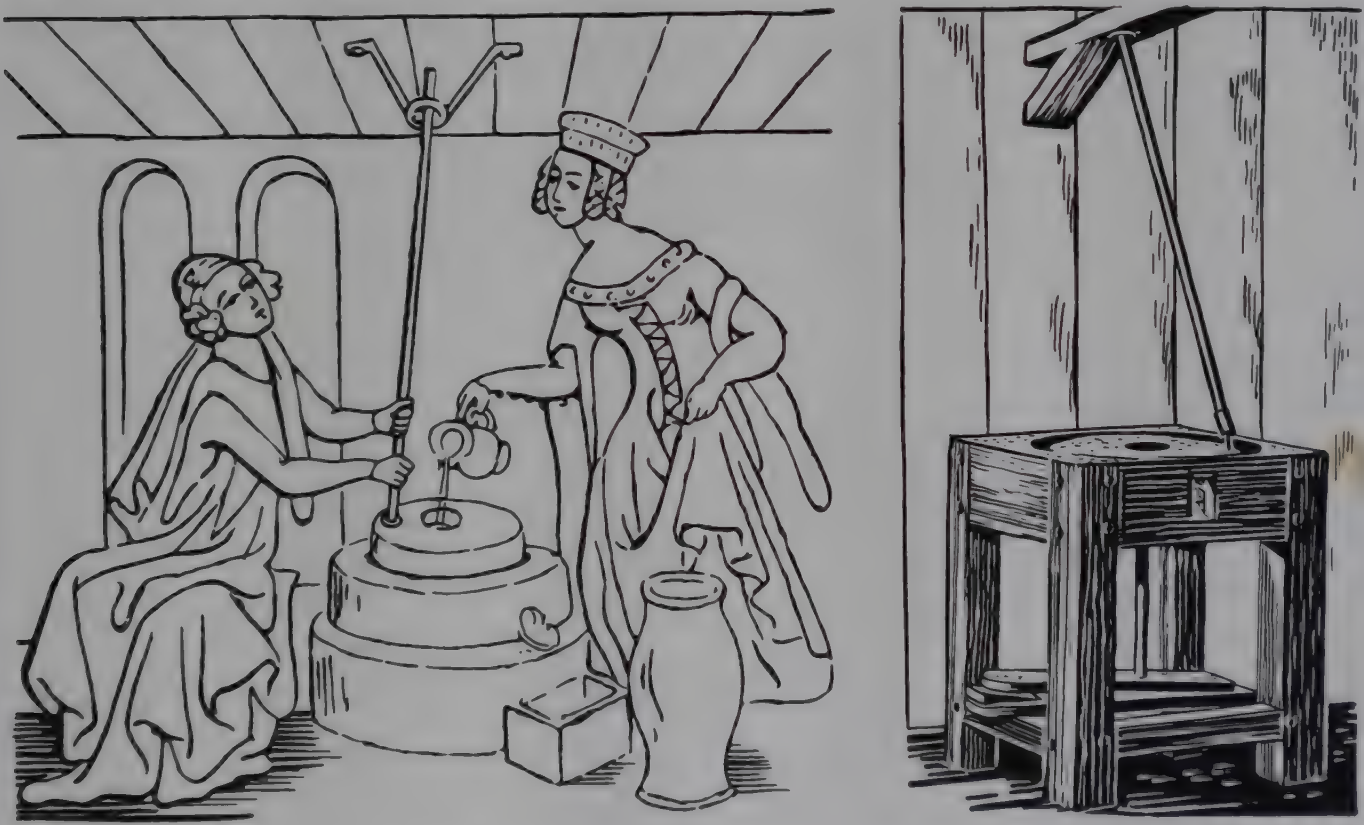
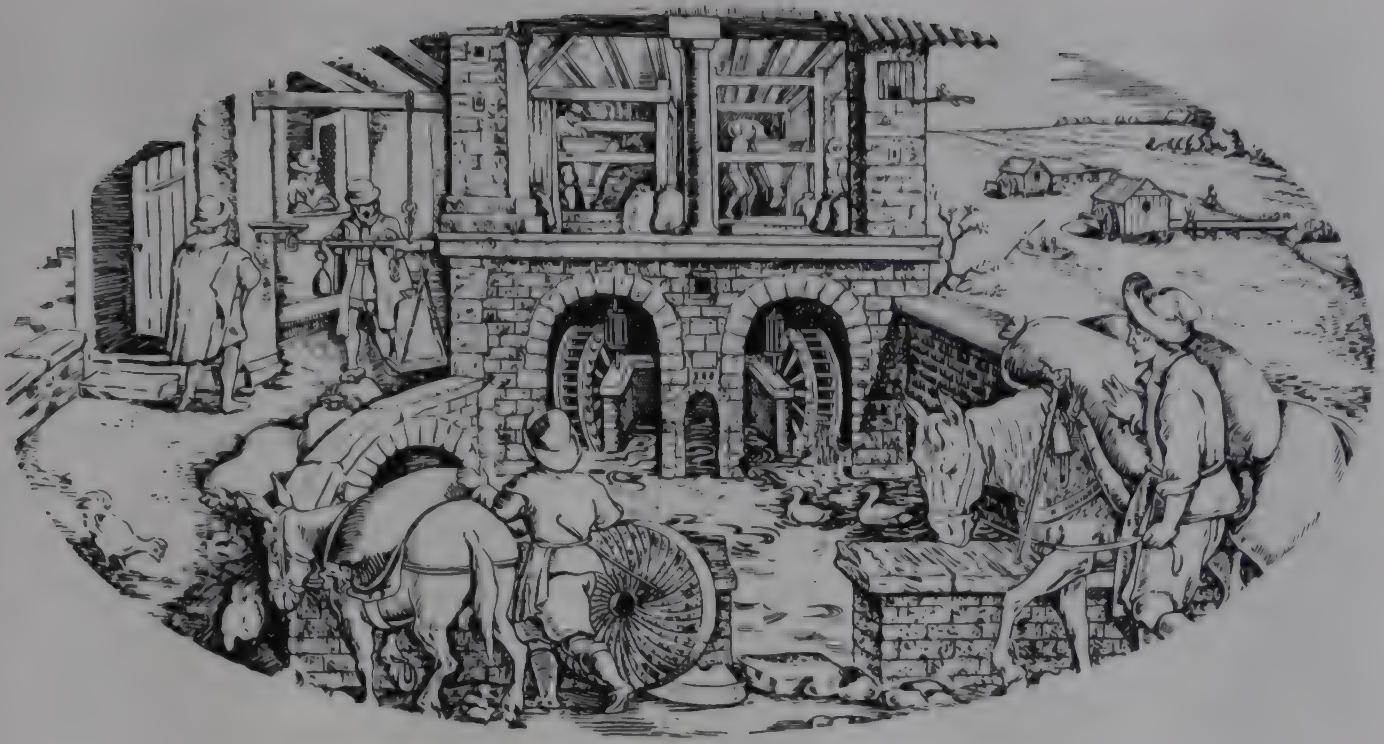


Figure 49. Pot querns. At left, from a German fourteenth-century manuscript. At right, an example from our southern Appalachians, on exhibit in the Bucks County Historical Society's Museum at Doylestown, Pennsylvania. Note the device for tentering the upper stone.

doubted whether the greater part of the grain grown by villeins or customary tenants, over England generally, ever came to the lord's mills." Still the prohibition remained in the law, so that it became advisable, even as late as the eighteenth century, for a number of great English municipalities to buy in the right to mill flour so that the large industry which by then had grown up within their limits should not remain under a legal taint.

Soke never became established in the American colonies, and querns were an occasional article of household furniture until about the middle of the eighteenth century. But as community milling grew up, domestic milling declined; and when, under industrialized milling, flour was more and more produced at central locations for sale over wide areas, the need for local milling began to disappear. But the quern persisted in regions out of touch with the march of industrialization, as, for example, in our southern mountain districts. Similarly in certain remote parts of Scotland, Wales, and Ireland, including the Shetland Islands, the quern is no doubt still in use. It is by no means an ineffective implement for hand milling.

But the greatest significance of the quern in our story is its position as ancestor of the powered millstone. In time it was realized that the upper stone could be rotated by means of an axle, which had a wheel at its other end, and that this wheel could be rotated in turn by the force of water. With the power sources of the machine thus separated structurally from the working parts, entirely new vistas of opportunity in milling were opened up.



CHAPTER VIII

Water Turns the Millstones

The water mill was the parent of modern industry.

—George Long

The mill stood as the embodiment of an idea of capital importance. This was the application of power machinery to industrial purposes.

—N. S. B. Gras

During the past two centuries steam, electricity, internal combustion fuels, and chemical energies have become so conspicuous in our world that we are apt to think of the power age as beginning with their introduction. It requires an effort to realize that, in fact, it began two thousand years ago with the invention of the water mill for grinding grain, and received a major impetus and redirection a millennium later when the winds were mastered for the same service.

Gravity was the first nonorganic force brought under human control and made to do useful work: first, by the simple means of paddle wheels placed in streams of swiftly flowing water, as nature provided them; soon, by means of larger and more skillfully designed wheels served by elaborately engineered systems of storage dams and sluices; much later, by means of huge turbine-type wheels which were turned by the currents of the

Chapter head oval. Water mill, from a German engraving of about 1570.

winds. In all these systems, the early engineers were dealing with gravity at second hand, as it moved water or air, and gravity itself as the activating force was not fully recognized until the seventeenth century. It was not until the nineteenth century that anything like the full power potential in the weight and pressure of moving water was developed, by means of scientifically designed turbines, penstocks, and channels.

But the millwrights who designed and built water mills and windmills for two thousand years, working on the practical basis of observation, experience, and trial and error, not only laid the foundations of hydraulic and aerodynamic sciences: they also made great strides in mechanical engineering. They learned how to collect energy at one point, transmit it to another – up or down and around corners – and there put it to work with a variety of motions, speeds, and forces. In this way they developed most of the basic principles of power transmission and utilization, and invented prototypes of many of the mechanical devices still employed in these arts. By the time steam power entered the industrial scene, water mills were operating in many lines of manufacturing, and existing mechanisms were available for rapid development to meet new needs. In the grinding of grain for food, a solid groundwork had been laid for the great technical and industrial revolutions of the past two hundred years, and so for the political and social changes that accompanied them.

The story of the power age begins, so far as reliable historical data are concerned, with a description of a water mill written by the Roman architect Vitruvius about 19 B.C., so concise that it can be quoted in full. He first discusses water-powered wheels for raising water, of the same type as

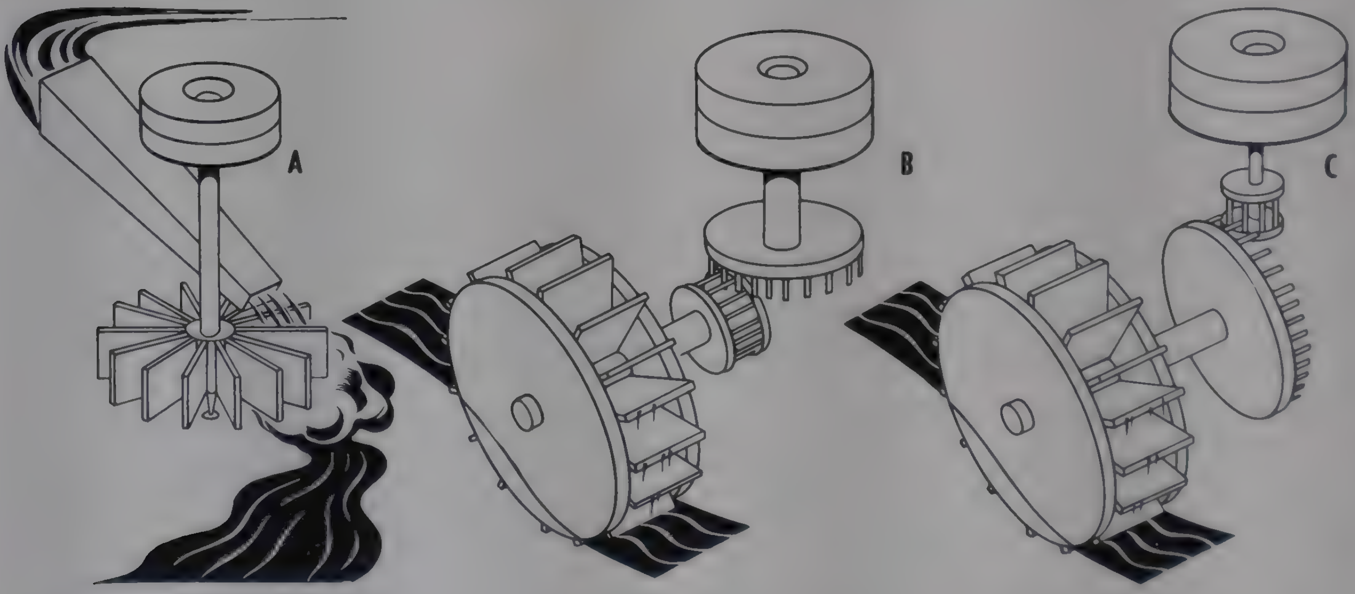


Figure 50. Types of water wheel. A, horizontal wheel with vertical axle, the direct-drive type. B and C, vertical wheels with horizontal axles. C is the type described by Vitruvius, although B was probably the one first actually employed. In B, the millstones rotate more slowly than the water wheel; in C, more quickly.

the man-powered *noria* of Egypt; these have floatboards similar to C of Figure 50, and buckets to catch and lift the water to a higher level, where they empty themselves.

He then continues: "Water mills are turned on the same principle. Everything is the same in them, except that a drum is fixed into one end of the axle. It is set vertically on its edge, and turns in the same plane with the wheel. Next to this larger drum there is a smaller one, also with teeth, but set horizontally and this is attached [to the upper millstone]. Thus the teeth of the drum which is fixed to the axle make the teeth of the horizontal drum move, and cause the mill to turn. A hopper, hanging over this contrivance, supplies the mill with corn, and meal is produced by the same revolution."

This mechanism, illustrated in Figure 58, combined a number of mechanical ideas, each with a substantial ancestry of achievement behind it, and a still greater future of usefulness before it:

1. The principle of turning a wheel by means of a current of water striking its paddles was not new, as Vitruvius explains; but in the device he describes, the power generated by the wheel is applied to work which has nothing to do with its source, the water—a departure opening up great vistas of usefulness.

2. Gears had been described by Aristotle in the fourth century B.C., and Ctesibius in the second century B.C. had used gears in various clock movements where the forces involved were extremely slight; but the Vitruvian mill is the first recorded use of gears in a massive mechanism designed for productive work. Here they turn a heavy millstone and twice change the planes through which the power is transmitted. Gears have been an indispensable feature of machine design ever since.

3. The Vitruvian mill shows a sound grasp of the lever principle of "force times distance," whereby the ratio between speed and force can be shifted at will. This gear train, like any gear train, can be explained as a series of levers, in this case interacting between the water wheel—itself a gear—and the millstone. The ratio between speed and force changes five times in Vitruvius' simple mechanism, and results in the millstone's revolving at a higher speed than the waterwheel that drives it. Actually, in all other early mills of which remains or records exist, the gear on the horizontal axle was smaller than the gear on the vertical shaft and the stone turned more slowly than the wheel (cf. Figure 56). It was not until later that the advantage of high-speed grinding was recognized and the Vitruvian ratio revived.

4. The Vitruvian mill used stones of the quern type, but increased power made it possible to enlarge them substantially. The upper stone was turned by a shaft running up through the center of the lower, fixed stone. This left the top of the upper stone free for the hopper Vitruvius describes.

Feed from this hopper had become continuous and automatic by the time the earliest drawings of water-mill mechanisms were made, and this may have been true of the Vitruvian mill—he does not say (Figure 52). In the automatic feed, an enlarged hopper was suspended over the upper stone as Vitruvius says, and this was equipped with a "shoe," or serving trough, at the bottom, to funnel grain into the grinding space. An agitator—at first merely a weight tied to the shoe and dragging on the turning stone, later a peg fixed in the stone and striking the shoe at each revolution—would shake out a quantity of grain. This agitator came to be called the damsel. By careful adjustment of shoe and damsel it was possible to regulate the flow so as to keep the mill grinding at a steady rate. Variations of this device remained in service as long as millstones were used.

The fact that the axle of the runner stone extended downward made it easy to install a crossbar underneath, whereby it could be levered up or down to "tenter," or adjust, the distance between stones, in spite of their great weight. This too became a permanent and essential device with all grinding stones.

5. For the first time we have, not a tool in human hands, but a true machine designed to transmit forces and accomplish useful work under strict control but without manual assistance or intervention in the work operation itself. In all earlier devices the manual element was dominant and indispensable. In the Vitruvian mill, for the first time, a craft was superseded by what we now know as machine production, and a movement was started which would culminate in the Industrial Revolution and the virtual elimination of the crafts as a source of essential goods and services.

The miller must be an expert, but for the first time we have the man who gets his results by pushing levers and adjusting controls—the first tentative pioneer in the direction of what many people today rather fearfully contemplate as the "push-button" world that appears to confront us. He opened two vastly extended avenues of development: one, the substitution of intellectual control for muscular effort and manual dexterity; two, emancipation from the human body as the measuring rod of what men can accomplish. With nonorganic powers under his authority and machine parts to take all their stresses and strains, there was no longer any theoretical limit to the size and scope of his productive activities. Naturally, it would take thousands of years to explore these possibilities, and we are still not within sight of the end. But if we can mark any beginning point at all, it will be in the mill Vitruvius described.

This mill was such an advanced mechanism that it is hard to believe that it did not have more elementary predecessors; and while its description is the earliest indisputable record of a water mill, there are older oblique references. We know that King Menuas of Urartu, where the early quern of Figure 39 was found, built a great canal in the eighth century B.C., and that at an undetermined early date there were forty mills of an unknown type along it. Strabo mentions a "hudraletes," or water-grinding machine, at Cabira in Asia Minor just before the middle of the first century B.C., and a few years earlier the poet Antipater seemed to indicate the existence of such a labor-saving device in his graceful lyric:

> Cease your work, you maidens who labored at the mill. Sleep now, and let the birds sing to the rosy morn. Ceres has commanded the water nymphs to do your work; obedient to her call, they throw themselves onto the whirling spokes, force round the shaft, and thus the heavy mill.

Also there is in existence a simpler, more primitive type of water mill which may have had an earlier origin, or may be merely a later backwoods simplification. This is a direct-drive mill, minus all gears between water wheel and millstones. The wheel was placed on a vertical axle and laid flat in a stream or in the path of water from a flume, so that the flowing water would rotate it by impact (Figure 50). The millstones were located directly above the water wheel, with the upper stone mounted on the axle and rotating at the same speed as the wheel.

A nice sense of logical development would be gratified if we knew that this type had appeared before anyone thought of standing the wheel upright for greater efficiency and introducing gears to change the direction of its transmitted motion. Its wide distribution gives some support to the possibility, but it is usually found in hilly regions, where the small, fast-flowing streams to which such a simple arrangement is best adapted may have suggested it to rustic craftsmen. The fact that it was introduced wherever the Norsemen penetrated in their excursions, from Norway to Ireland, led British nineteenth-century antiquarians to assume that it had originated in Norway and so to give it the name of the Norse mill. Jardine counted fifty-one in use within an eight-mile radius in Scotland in the nineteenth century, and the example in the Museum of the Bucks County Historical Society at Doylestown, Pennsylvania, was taken out of service in the Carolina mountains only a quarter-century ago: it was purchased from an owner who left it untended in the woods, available to anyone who wished to grind his meal on the self-service principle.

Figure 51 reproduces a mill of the Norse type, from Lewis in the Hebrides, with the upper stone cut away to show how it was mounted on its axle. This mill, in common with other northern examples, rotates in a clockwise direction, whereas direct-drive mills of the eastern or Greek type run counterclockwise. The paddles of northern water wheels are usually flat, whereas most Greek-type direct-drive mills are fitted with scoops to catch the water. Direct-drive mills permit only small-scale operation; the stones used are always of reduced size – down to about 27 inches across –

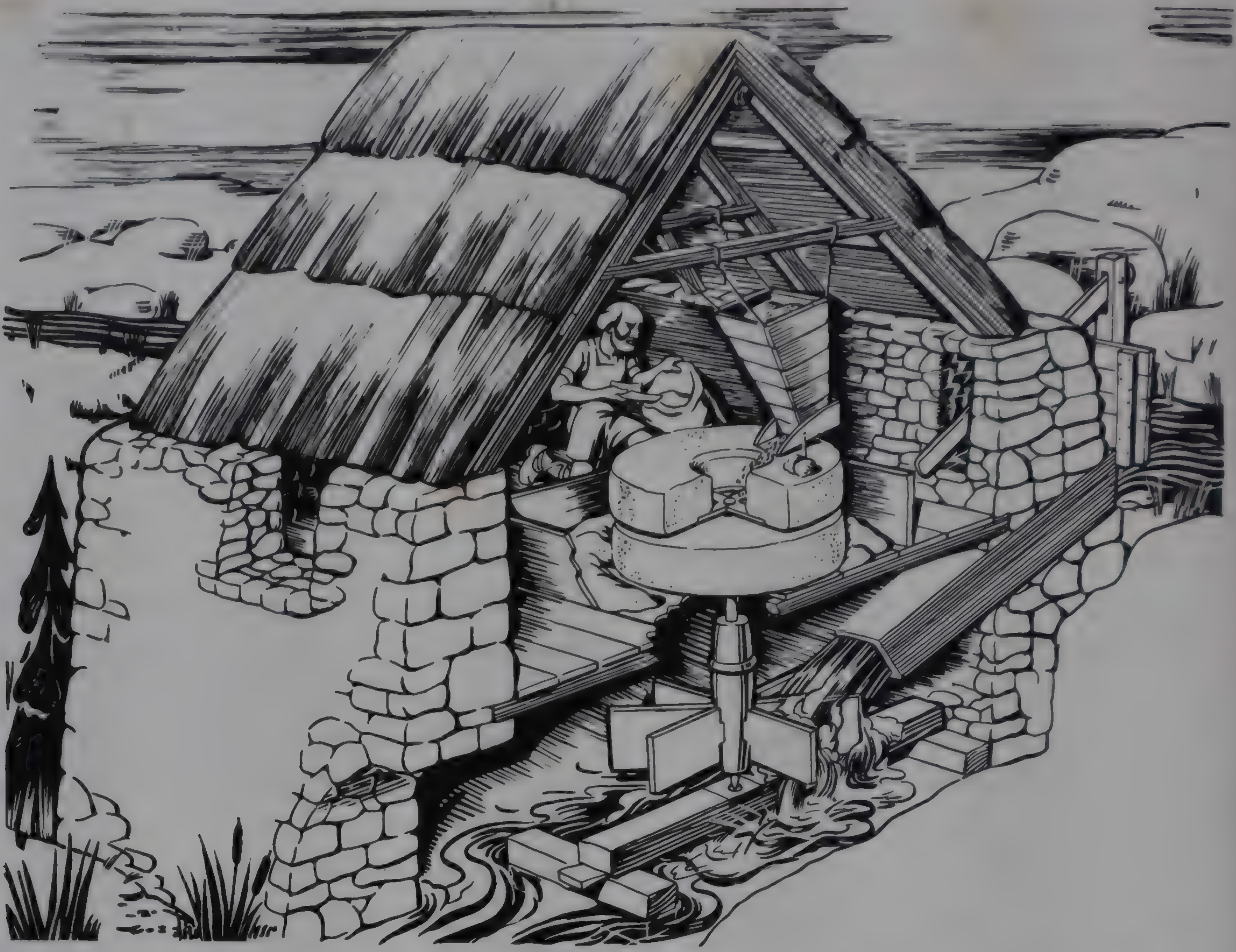


Figure 51. Norse-type direct-drive mill, from Lewis in the Hebrides Islands, off the Scottish coast. The runner stone has been cut away to show how it is mounted. Notice the rock used as a "damsel" to agitate the shoe of the hopper. The water wheel of this mill is served through a flume, though many mills of this type are located directly in the stream. A gate can be dropped to shut off the water from the flume.

and rotation is slow. Their feed is automatic if the hopper is equipped with a simple stone-agitated damsel, like the one shown in the Lewis mill.

The prime achievements in the Vitruvian mechanism as compared with any direct-drive mill were, first, the recognition of the fact that a wheel placed vertically in a stream was more effective than one placed horizontally—which would be true so long as the principles of the turbine remained unknown; and, second, the introduction of gears between wheel and millstone. By these feats of pure reason, the aimless onward rush of a stream of water was translated into a steady and purposeful operation, and a machine of immense potentialities was produced. In time it would be used to drive saws, full cloth, run ironworks, pump water, crush ores, pull wire—to name only a few of its more important services. Finally, about 1700 in Sweden, it was adapted by Christopher Polhem to what was probably the first powered factory, to manufacture an extensive line of metal tools and objects involving the use of rolling and shearing machines and a variety of specially invented devices.

In spite of these potentialities, the Vitruvian mill was so radical an advance, and so little related to the attitudes and social patterns of its time, that many decades passed before it came into general use. The early mills were no doubt highly imperfect: we know, for example, that the overshot water wheel of a fifth-century Athenian mill (Figure 56) received its water from too great a height, and that its moving parts rubbed against the stone walls of its enclosure. In addition, the water mill required a large capital investment in a society where slaves and animals were cheap and plentiful. No classical writer celebrated the importance of the invention – a fact easier to understand than its neglect by modern historians.

Nevertheless the new machine won acceptance, especially where manpower was less expendable: Ausonius mentions water mills on the Moselle in Gaul in the third century A.D., while the first known English reference, in a charter of Ethelbert of Kent, dates from 762. It is possible that water mills were introduced in England centuries earlier, although Anglo-Saxon references are rare; the census of the Domesday Book (1080–1086) records 5,624 mills in the country, of which by far the greater number were certainly water mills, all or nearly all of the rest being driven by animals. By that time water mills could be found on almost every running stream in all hilly parts of Europe and adjoining lands, while in flat countries the windmill was already being introduced. Both the water mill and the windmill were carried by Europeans over almost the entire globe in the great expansion of European civilization which began to gather momentum in the fifteenth century.

It is not surprising that purely rule-of-thumb methods of invention resulted in slow progress toward a correct solution of the many obscure mechanical and hydraulic problems involved in a water mill, but decided progress was made over the centuries nevertheless. For instance, it was observed that the horizontal axle of the water wheel, when extended into the mill to a point below the millstones, was subjected to a very great torque, or twisting stress, and being of wood, both the axle and its supports had to be made extremely heavy to stand the strain. This condition was relieved by shortening the axle and introducing a new pair of gears, evidently a long-established practice when Ramelli's drawing of 1588 (Figure 52) was made. A small gear was mounted as close as possible to the water wheel, and this drove a "great spur gear," which in turn drove the gear on the lower end of the grinding stone shaft. From a single great spur gear more than one millstone could be driven.

This arrangement had the additional advantage that the intermediate gear could be used as a clutch to disengage the millstones from the water wheel. Previously the millstone gear, with the millstone, had to be lifted out of mesh with the drive shaft gear, if the stone was to be stopped without stopping the water wheel. The intermediate gears also allowed

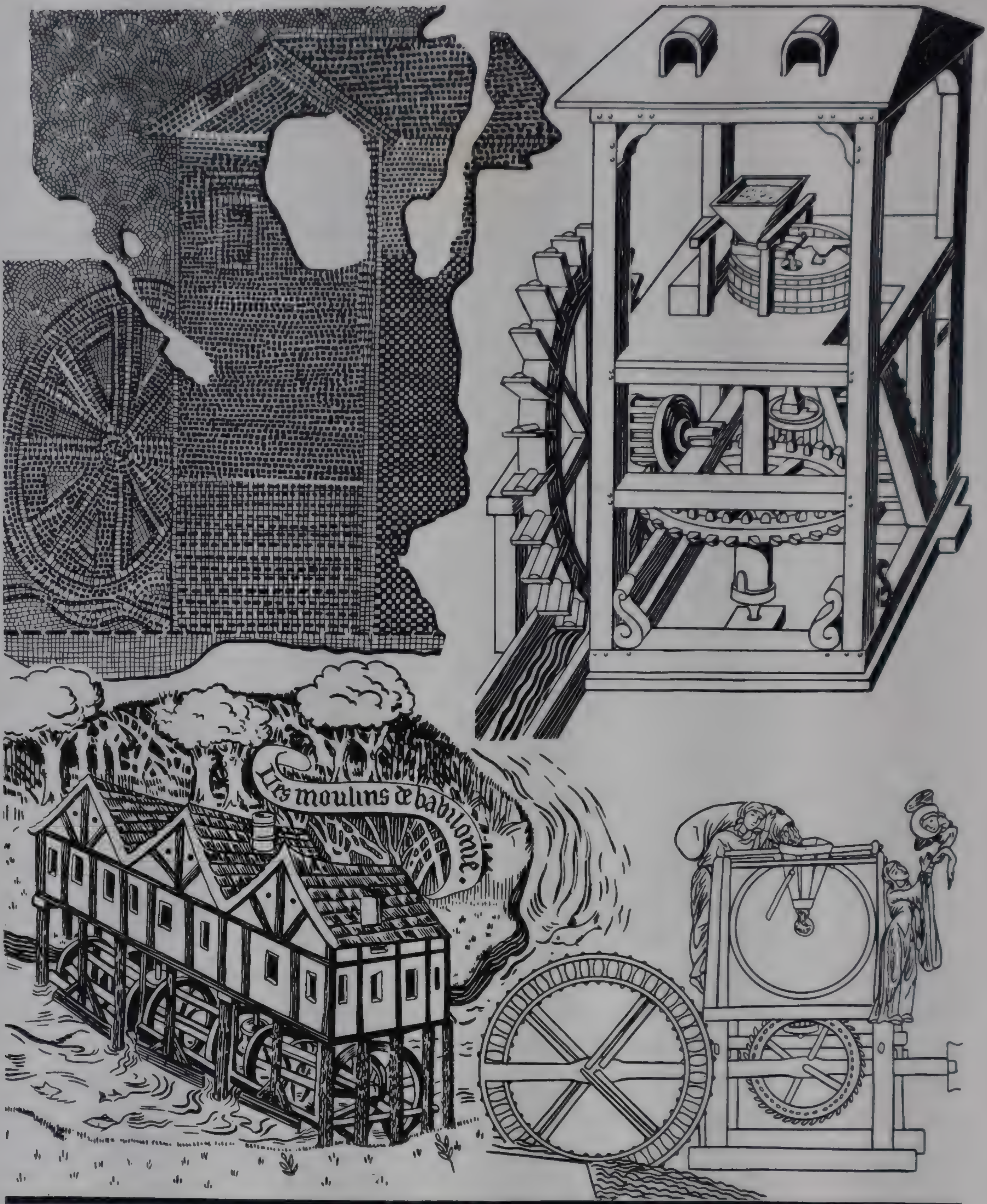


Figure 52. Undershot water mills. Upper left, Byzantine fifth-century A.D. mosaic—the first known depiction of a water mill. Lower right, mill from the *Hortus deliciarum* of the Abbess Herrad, from about 1160. Note the multiple perspective which places each circle head-on. Lower left, a "mill of Babylon" from a fourteenth-century French MS in the British Museum, illustrating the tendency to interpret former times in terms of the present. Upper right, Ramelli's depiction (1588) of an undershot mill with an extra pair of gears. Note the double row of pegs in the great spur gear, and the rod to agitate the hopper shoe.

more exact control of grinding speed. Without them, an accelerating gear tended to turn the stones too rapidly – a fact which probably accounts for the lateness with which accelerating gears were generally adopted.

In the eighteenth century a further improvement was made when the gear on the axle was enlarged to approximately the same size as the water wheel, in addition to being set as closely as possible to it. Then, if the power was taken from this large first gear on the same side as the loaded side of the water wheel – the side, that is, which bore the weight of the water – and a little below its center of gravity, there was practically no torque whatever on the axle. With this arrangement, the last traces of heavy construction could be eliminated, and the water wheel could be suspended and supported by braces only. This was important at a time when water wheels generally were 17 or 18 feet in diameter.

All early gears were of wood, in two forms – a "lantern pinion" made by setting "rounds" or "staves" between two solid discs, and a spur wheel made by setting a row of pegs upright in a single flange. Sometimes a spur wheel bore both a vertical and a horizontal row of pegs, as in Ramelli's drawing of Figure 52, in order to take power from a vertical pinion and transmit it to a horizontal pinion – as would be done today with bevel gears.

The lantern construction was used for small gears, where the total force acting on each stave during a day's run would be very great and the staves therefore must be firmly held; the single flange construction was used for large gears, where the force would be divided among many staves meshing with a lantern gear. Both are still used in the water-powered sections of certain very large modern milling establishments, and are considered superior to steel gears in transmitting a smooth, even flow of power.

This smooth action was accomplished by an ingenious arrangement. Wooden gear wheels were far from precise in their dimensions, but the millwrights managed to make them so through normal wear: the main spur gear might have sixty-one staves, and if so the lantern pinion which engaged it would have ten. The reason for giving the spur an extra peg, called the "hunting cog," was this: "that, as every cog comes to the trundle, it may take the next staff or round behind the one which it took in the former revolution, and thus it will wear all the parts of the cogs and rounds which work upon one another equally, and to equal distances from one another in a little time; and to make a true uniform motion throughout the whole work."

Since true, uniform motion was essential to a smooth and even grind, a constant, uniform flow of water was also necessary, and a great deal of clever engineering went into providing it. Waterfalls and rapids were eagerly sought for mill sites, and many cities, towns, and villages in America as well as abroad owe their locations to the fact that nature had arranged a precipitous drop in a stream's level there: as Rochester, New York, grew up around the great falls of the Genesee River, and Minneapolis around the Falls of St. Anthony. The fall itself was seldom used directly, but water from above it was conducted in more easily regulated quantities through races or flumes to mills below it. Even under these circumstances, it was often necessary to add a dam for storing water against a drought. In flatter regions the dam often was built at a considerable distance above the mill in order to obtain a sufficient drop. This meant that the millrace had to be built with elevated banks or levees, to hold its water at approximately the same level as the pond until it arrived at the mill wheel. The building of satisfactory dams, races, flumes, and sluice gates called for a commendable degree of practical engineering skill.

For its times, water milling was what we now call a heavy industry. A fair-sized stone was about 4½ feet in diameter, 8 or more inches thick when new, and weighed about 1,500 pounds, while large stones ran up to about 7 feet. Stone from local quarries was used in many mills – peak stone quarried in one piece in the northern counties of England, for example, stone from Mt. Tom in western Connecticut in our New England states, or Ohio stone farther west; but proper stone was so important that it was frequently imported, sometimes at considerable expense. Early English millers shared the Roman preference for stone from Andernach on the Rhine, known as blue or cullin stones – *cullin* being a corruption of *Cologne*. But French buhr (or burr) from La Ferté-sous-Jouarre and Bergerac, near Paris, came to be preferred in the eighteenth century wherever good milling was appreciated, and was imported in quantity even into the United States. An irregular network of quartz cavities running through this stone keeps its grinding surfaces sharp as the stone wears down. For economy's sake, small blocks of buhrstones were cemented together with plaster of Paris and bound with an iron band to make a millstone, the buhr being used only for the thickness to which the stone would be worn in grinding.

The under or bed stone of a pair of millstones was set in position on packing pieces in a strong timber frame; as the stone wore, thicker packing could be inserted without shifting the frame. The runner stone was mounted on its shaft in one or another variation of the rynd form exhibited in Roman hourglass mills (Figure 42). Late mountings permitted an adjustment of about one inch in either horizontal direction. The two stones were surrounded by a casing standing about six inches away from their circumference, and a brush attached to the runner stone swept the ground material around to a spout which poured it directly into a sack or, in more complete mills, carried it to a bolting or sifting machine.

For good grinding the runner stone had to be very exactly balanced over the bed stone – ideally there should be no contact between them. Finch quotes an old miller to the effect that the stones should grip a piece of brown paper at the eye, a piece of newspaper farther out, and a piece of tissue paper at the skirt — no doubt an exaggeration, though an indication of an ideal. Holes were sometimes sunk in the four quarters of the top of the runner stone, into which sufficient lead could be poured to bring it into balance. The running balance of a millstone might not be the same as its standing balance, and so weights set on screws were often fitted into these holes, to be raised or lowered, moved in or out, until the stone was in running balance.

Methods were found to tenter the grinding stone very minutely and with least disturbance to its balance. The vertical drive shaft of the running stone was supported on a crossbeam, called the bridge tree, which had one end set in a wall and the other in a second crossbeam, at right angles to it, called the brayer. The brayer in turn had one end set in a mortise, and the other was suspended by an iron rod which went up through the mill floor and was supported there by a screw nut. Thus the miller, with one eye on the millstones beside him, could turn the screw nut and make the exceedingly slight adjustments of spacing which good grinding required.

The dress given to the grinding surfaces was extremely important. As Oliver Evans pointed out, a dull stone "kills or destroys that lively quality of the grain, that causes it to ferment and raise in the baking; it also makes the meal so clammy that it sticks to the cloth and chokes up the meshes in bolting."

The floury part of the kernel should be reduced to as fine a powder as possible, without overheating and without being subjected to undue pressure. In addition to their cutting function, the grooves of a dressed stone ventilated it, helping to keep the meal cool as it passed outward toward the circumference.

Figure 53 shows a millstone dresser at work, and the inserts above show various types of dress. Top and bottom stones were dressed identically, so that a shearing effect between the furrows on the two stones was obtained when the runner was reversed and rotated over the bed stone. In the most common type of dress, the surface of the stone was trued and divided into sections or "quarters" — ten in the case of the stones illustrated in Figure 53 — and each section was cut by a master furrow and a number of subsidiary furrows. None of the master furrows pointed directly toward the dead center of the stone: in a stone running counterclockwise they were tangent to the left-hand edge of the millstone eye, to the right-hand edge if it ran clockwise.

It was generally agreed that the furrows should consist of a vertical edge on their leading side and a feather edge on the other, connected by a slanting surface, as shown in the cross section of Figure 53. But high debate raged over such questions as the depth of the straight edge, the width of the furrow and, above all, the degree of sharpness of the feather edge; for it was just at the feather edge, for the most part, that the berry would be either sheared or crushed, making either a lively flour or an unresponsive product. It was also usual to "face" the lands, or spaces between the furrows, by cutting fine tiny grooves into them.

These characteristics had to be worked out on the basis of analysis checked by results, since the action of the grooves could not be observed directly by the early dressers. Today we can see their shearing action by marking transparent discs in the same way, and the efficiency thus revealed is remarkable. Because the grooves are not true radii, but start off center, they do not meet in parallel but pass each other at an acute angle which moves continuously outward with a *cutting* effect. In this they resemble the cutting edges of a pair of shears, which also are off center with respect to their pivot. In fact, what the dresser accomplished on the surface of

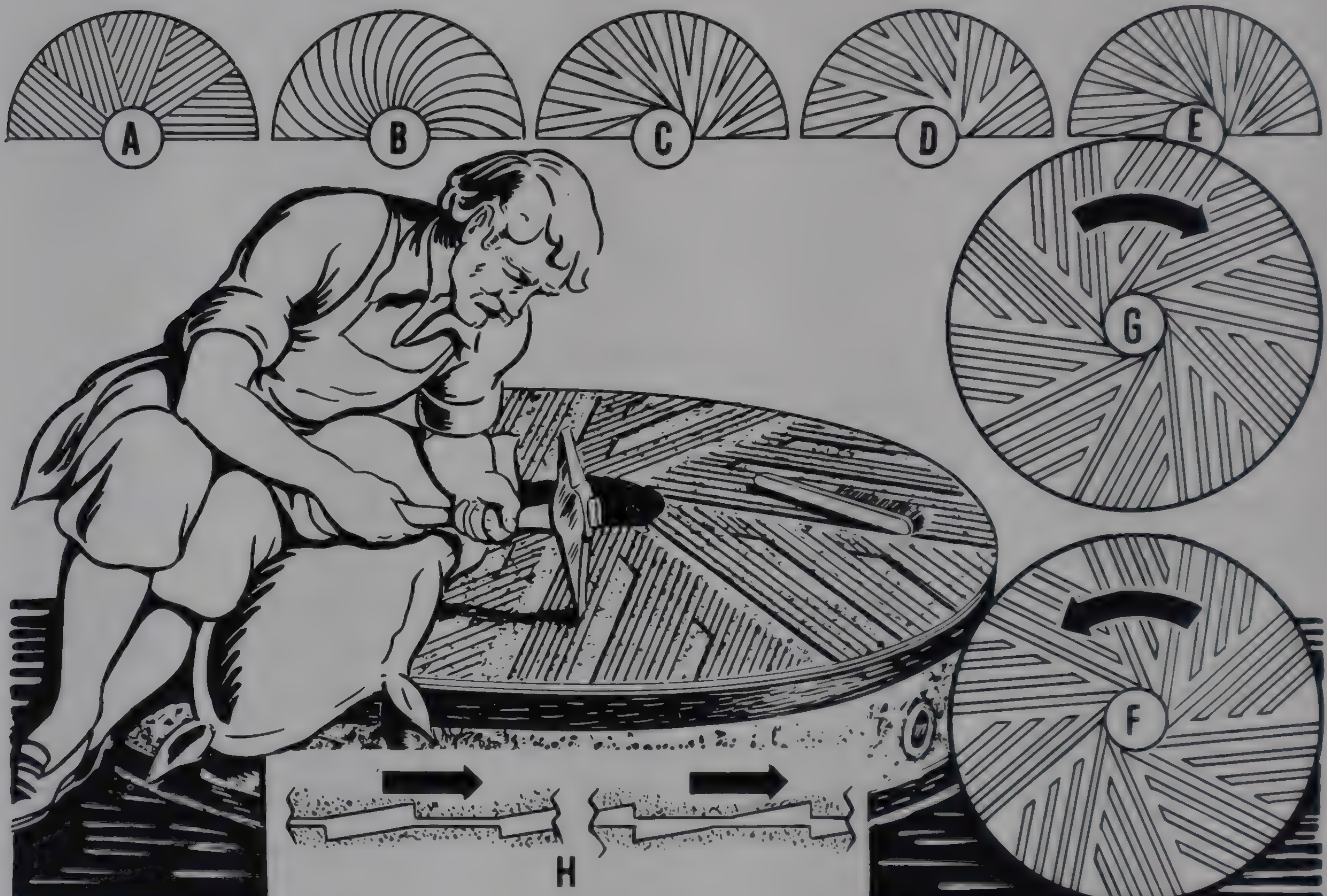


Figure 53. Millstone dresser at work. He is grooving the lands between the furrows, with his left arm resting on a sack of meal and his right hand guiding the mill pick. Above, some varieties of millstone dress. A, late Roman from the fourth-century A.D. Saalburg castle. B, from Leupold's *Theatrum machinarum molarium* (1735). C–E, nineteenth-century dresses: C, two-furrow or "two-quarter" dress; D, "three-quarter" dress; E, straight or union dress. F and G, right-handed and left-handed stones, for clockwise and for counterclockwise rotation, in four-quarter dress; the arrows indicate the rotation of the stone when turned over. Upper and lower stones of a pair are dressed identically. H, enlarged view of the relation between lands and furrows during rotation.

stones F and G in Figure 53 was to construct forty pairs of shears of varying length – ten making the first cuts on the berries at the eye of the stone, all forty at work in the final grind near its edge. The result was not only to cut the wheat berries progressively, but to move them outward continuously toward the circumference of the stones. To see this arrangement in action is to feel genuine respect for the artisans who worked it out experimentally.

A special hoist engaging holes in the sides of the runner stone was needed to lift it off for cleaning and dressing. It took two or three days to dress a pair of stones well, and during constant use this was advisable about once every two weeks; Evans, in fact, advocated two lighter dressings a week. Millstone dressing was done by itinerant craftsmen who possessed an unusual combination of experience, skill, and patience. Even today we use a phrase which indicates the respect in which dressers were held: "to show one's mettle" originally meant "to show one's metal." In England "metal" is a name for crushed stone. The phrase referred to the bits of stone which had become embedded in the dresser's left hand during the course of many years' work; to show them proved that the possessor was a man of experience and responsibility.

A number of auxiliary drives and devices came to be commonly employed in both water mills and windmills. It became usual, for example, to take power off the rear end of the drive shaft of windmills for a pulley to hoist the unground grain up to the level of the hoppers. In water mills a system of shafts and gears could be arranged for the same purpose. The hopper was usually fitted with a warning bell, or "warbler," which dropped onto the top of the runner stone when the grain got low, and danced about to warn the miller that his stones would soon be running empty.

Progress in the second phase of the milling process, the purification of the flour after it has been ground, lagged far behind the grinding art. Although the Romans had used sieves, the Anglo-Saxons were unacquainted with this refinement until long after they had left the continent to establish themselves in Britain in A.D. 449. *Gratan* meant to them not separated groats or cracked fragments, but coarse, unground grain; there is no common Germanic name for bran, the coarse remainder after the flour has been sifted – the root of the word is Celtic. The progress of milling practices can be charted roughly by the dates at which new terms were added to the glossary of milling.

The Anglo-Saxon word *melu*, meaning meal, came into use in Britain; it is related to *mill*, *molar*, and even to the Hittite *mallanzi* (grind). Sifting was an established practice before the Norman conquest in 1066, as evidenced by the differentiation between very fine flour – *smedma* – and good flour – *grytt*. That this "good flour" was not so very good may be suspected from the fact that *grits* has survived in use today to designate coarsely ground grain. By the time of the Conquest, a fine hair sieve had

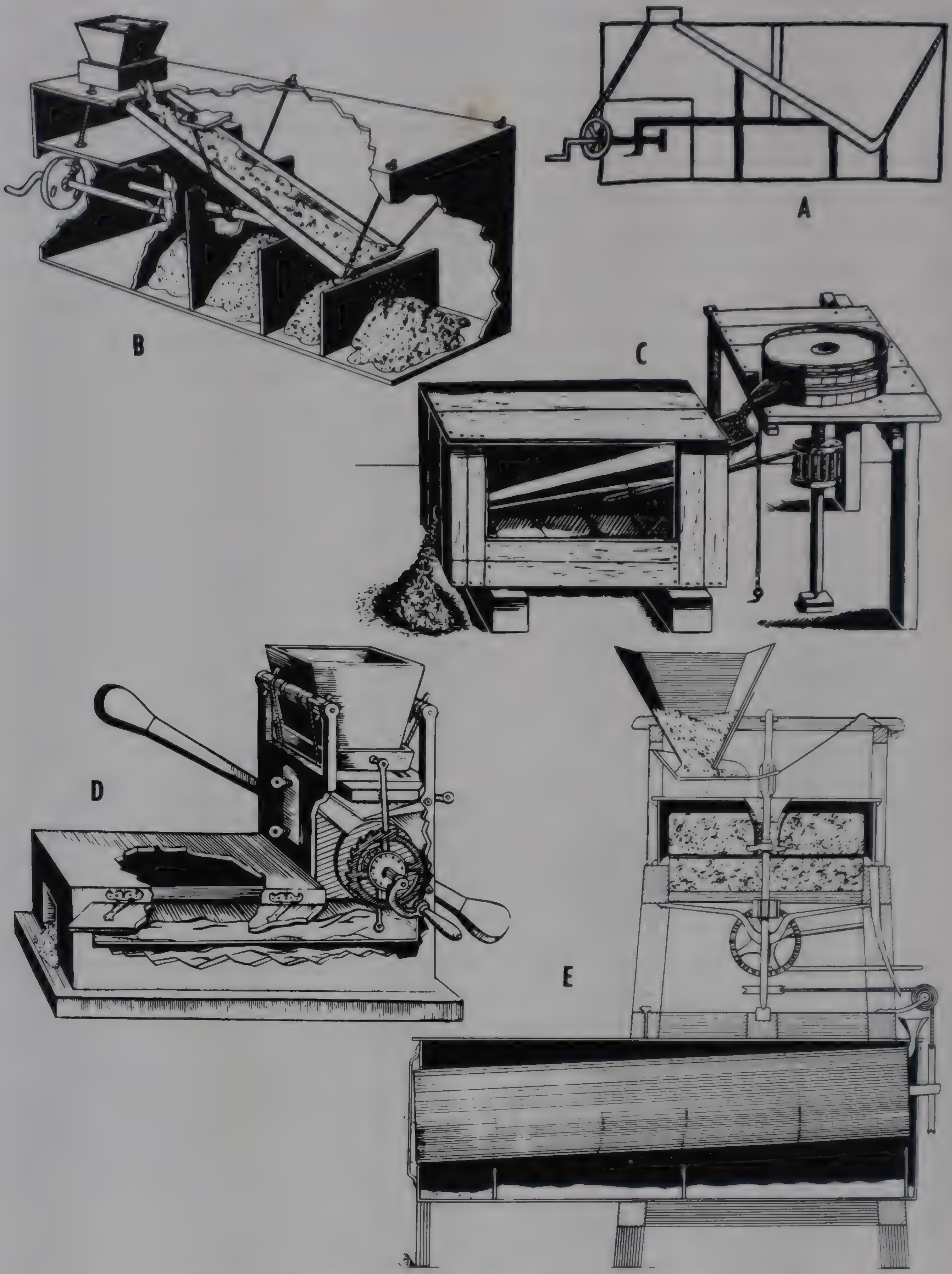


Figure 54. Hand-milling and bolting machines. A and B, Cardan's 1557 diagram of a hand-agitated bolter, and a perspective interpretation of his machine. C, Veranzio's early seventeenth-century device for automatic agitation of a bolter, probably very similar to Boller's 1502 invention. D, Böckler's 1662 milling and bolting machine. E, Charlemagne's 1793 milling-bolting combination, which makes considerable use of iron parts.

come into use, and was called a temes; as *temse*, the word and the sieve are still in use in certain parts of England.

These temse were simple, square, and boxlike sieves, and were held in the hands and shaken, but later their capacity was increased and they were sometimes used in a series of graduated fineness, and shaken more systematically by a crank device, as typified by Cardan's diagram of 1557 (Figure 54). There are those who believe that this practice gave rise to the phrase which is now current as "He'll never set the Thames on fire," meaning that the person in question does not have a superabundance of energy: a too energetic boy turning the wooden machinery of the temse sometimes set it on fire by excessive friction. As the original word and the process ceased to be familiar, "temse" was replaced by "Thames."

An important advance, credited to Boller in 1502, was the use of mill-power to shake the sieves. Boller's device was probably similar to Veranzio's, shown in Figure 54, where a stick striking against a lantern gear agitates an inclined trough covered with cloths of different meshes. These sieves came to be called "bolters." "Bolting cloth" was an extremely hard material of even weave, originally of linen or cotton, and from the eighteenth century often of silk, in which the mesh might be as fine as one

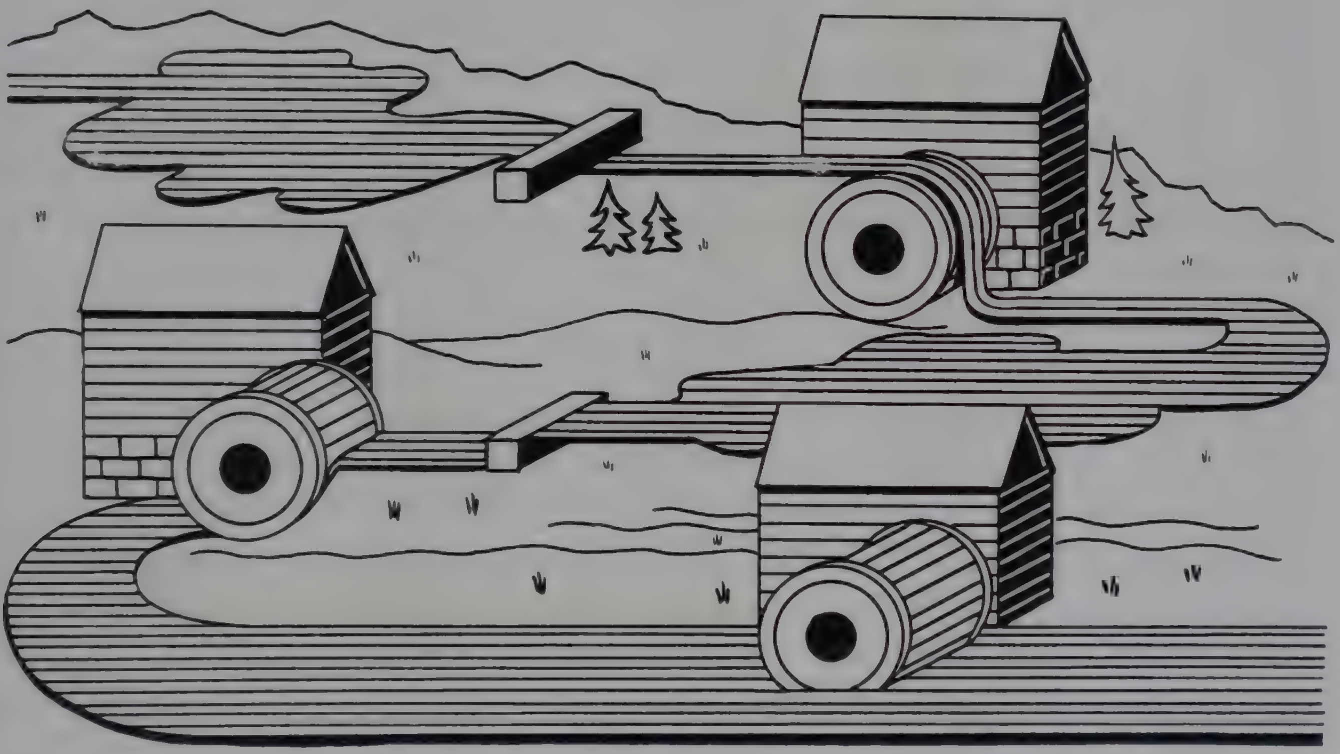


Figure 55. Varieties of water wheel, and typical locations for each. Above, overshot wheel, rotated almost entirely by gravity; typical position in upper reaches of a stream, below a dam. At the left, breast wheel, rotated by a combination of gravity and impact of the water; typical position in middle reaches of a stream, below a dam. Below, undershot wheel, rotated by impact; typical position in lower, wider reaches of a stream, no dam required; if the stream is narrowed to receive the wheel, energy is lost, since the wheel will not rotate at the speed of the stream.

hundred threads to the inch. The agitation of the bolter screened the finer particles of flour through the cloth, which overtailed the coarser.

Boller's invention was not universally adopted at once: Figure 54 shows a mid-sixteenth-century hand-agitated bolter described and diagramed by Cardan, as well as later hand-operated milling machines equipped with bolters; in that of Charlemagne (1793) the cylindrical bolter, rotated by the power drive, was a considerable improvement over the trough type. The first record of a cylindrical bolter is to be found in Ramelli (1588). This and the other bolters we have illustrated also evidence the growth of interest in finer grades of flour — Cardan's hand bolter produced four types of material, from fine flour at the head of the machine to rough animal feed at its tail.

The problem that puzzled millwrights longest was the efficiency of the water wheel itself. Here direct observation was misleading; it was impossible to check power output exactly by any means available at the time, and conditions at different mills varied so much that no uniform standards of performance could be agreed upon. So millwrights and millers failed over nearly two thousand years to agree about the best use and the relative efficiencies of the three main types of water wheel — the undershot, overshot, and breast wheels illustrated in Figure 55. The wheel described by Vitruvius was undershot, but some early wheels were overshot. The earliest known instances of both, in fact, date from the fifth century A.D. — the undershot wheel pictured in a Byzantine mosaic, Figure 52, and the overshot wheel which was located in the Athenian agora, shown in the reconstruction of Figure 56. The first mention of the breast wheel that has come to our attention is in Fitzherbert's *Boke of Surveying* (1538); it is apparently a late variation.

Reliance on direct observation made it natural at first to prefer undershot wheels: there was a great deal of water involved, and its splashing and hurly-burly could clearly be seen, demonstrating its power. In the overshot system a much smaller stream merely filled the buckets, turning the wheel under the water's dead weight. It was with the idea that impact would assist weight that the water from the flume in Figure 56 was poured onto the wheel from a height, and for centuries overshot wheels were served in this way. Zonca's 1607 design (Frontispiece) is typical. It was not until 1787, in fact, that the correct dynamics were first defined by L. N. M. Carnot: "For maximum efficiency the fluid must enter the engine without impact and leave it without velocity." This principle is in complete contradiction of appearances, although it agrees with the dictum that the most work is done with the least fuss.

In the seventeenth century the notion of force was born, and it was realized that the distance through which a force acts is no less important than its magnitude. Weight was seen to be a factor of the force of gravity.

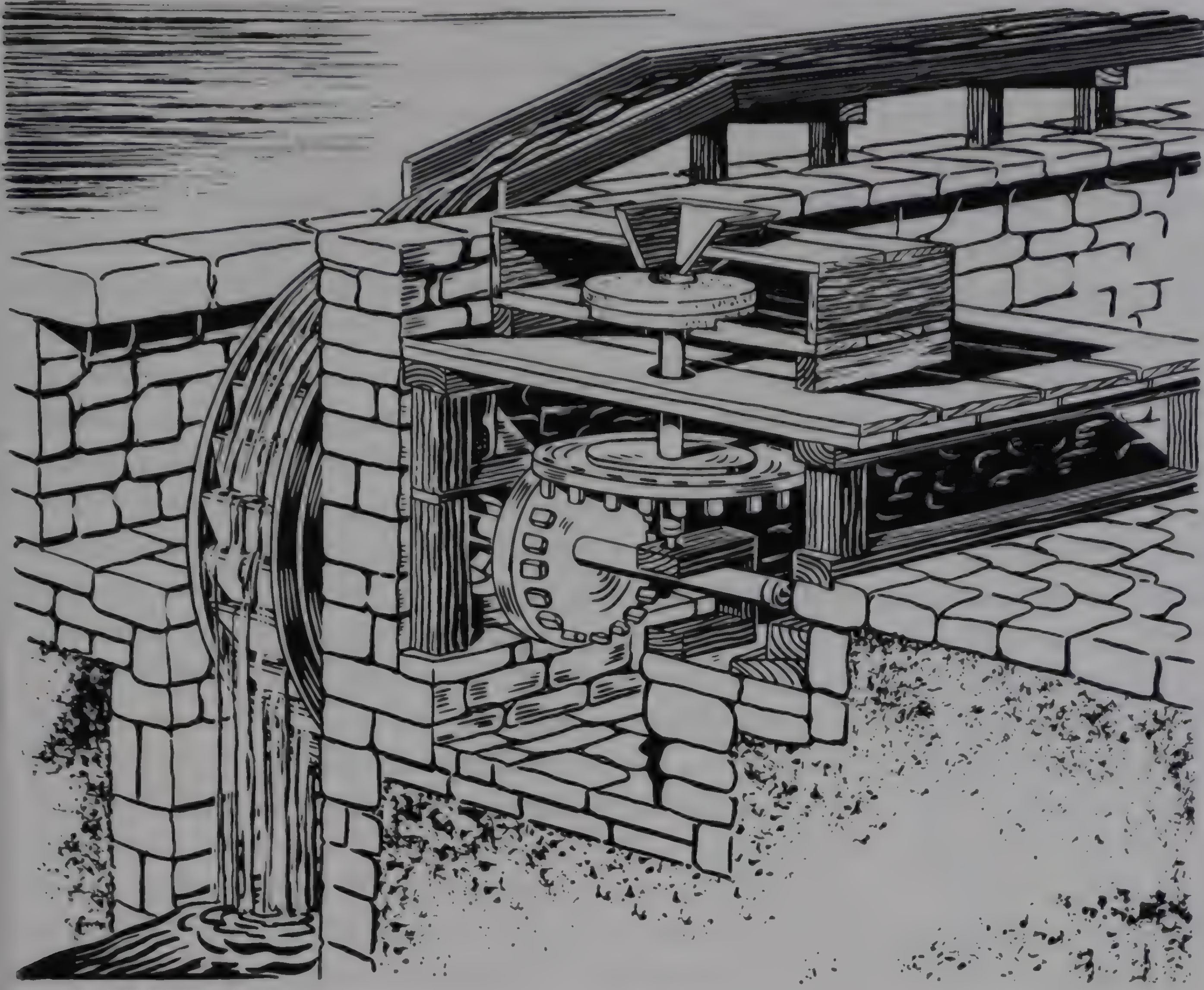


Figure 56. Reconstruction of an overshot mill which was operating in the late fifth century A.D. in the Athenian agora, or market place. The dimensions are known from evidences left in the stones of the ruins. Note the thinness of the millstones, and the fact that by reduction gears they would rotate more slowly than the water wheel (compare Figure 50). The mill could be stopped by removing the slanting section of the millrace and so causing the water to drop behind the wheel.

and the tendency of a falling body to accelerate continuously was understood and measured. The superiority of an overshot mill was easier to realize with these principles in mind, for water in the buckets of an overshot wheel can be made to act over a greater distance than the water against the paddles of an undershot wheel of the same size, as Figure 55 will show. It was for long not realized, however, even by engineers, that each type of wheel was adapted to particular situations, and so the relative merits of overshot and undershot wheels continued to be argued. In the early eighteenth century, Desaguliers held that the undershot wheel was ten times as efficient as the overshot under identical conditions, while Belidor claimed that the overshot wheel was six times as efficient as the undershot — a sixtyfold difference of opinion.

In spite of divergent opinion, however, a body of doctrine slowly grew up on the basis of the practical experience of countless millwrights and mechanics and practical mill men, setting forth the best sizes and speeds of rotation of water wheels under various conditions, for use with millstones of given sizes, under different stream conditions. Figure 55 sums up some of these more general conclusions. But scientific proof could not confirm this accumulated experience until it was possible to conduct controlled experiments apart from actual milling operations. Toward the middle of the eighteenth century, John Smeaton found the answer for all practical purposes by rigging up a small model wheel which could be served a measured flow of water under any desired set of conditions. Smeaton brought a considerable fund of practical experience to his work and tested his conclusions in actual practice; and his studies determined with reasonable precision the relative efficiency of various types of wheels and various methods of serving water to them.

Smeaton discovered that if the total power delivered to each of three water wheels be represented by one unit, an overshot wheel could transmit about six tenths of it and an undershot wheel about three tenths of it, with the breast wheel rating between the two. That impressive commotion in an undershot wheel wasted about one third the power delivered to it, and it reached maximum efficiency when it rotated at about one third the flow-speed of the water if the latter was rapid, or at about one half the flow-speed if the volume was great. With an overshot wheel, it did no good to have the water reach it at a velocity more than slightly greater than the speed of rotation at its circumference.

Even after Smeaton's work, the actual problem of deciding on the type and size of wheel for a particular situation was far from simple, especially as millwrights began to improve each variety. For a given fall of water more work could sometimes be done by a breast wheel carrying full buckets than by an overshot wheel whose buckets started about half-full and began to lose their water long before reaching the bottom of the revolution. This did not contradict Smeaton's conclusions, which applied to the effects obtained from equal volumes of water, but it left many a miller sorely puzzled. More water could be handled efficiently in either type by curving the bottom wall of each bucket; and it was also advisable to provide air escapes near the top of breast-wheel buckets, so that the air trapped in them would not act against the entering water. The first wheel ventilated in this way was designed in 1828.

Additional refinements further altered the situation. In the early nineteenth century, for example, Fairbairn pointed out that the diameter of the wheel could often be increased if it was made breast type rather than overshot, because its bottom could be immersed in the tail race, where flow would be in the direction of rotation rather than against it as with the overshot wheel. Sometimes the effective height of the fall could be increased by dropping the tail race a few feet and leading it off underground to a lower level in the stream. The increased availability of iron helped these changes by making it possible to construct larger wheels than could previously be made economically out of wood. Also a breast wheel could be provided with an adjustable sluice – even with one that automatically adjusted itself according to the speed of rotation of the wheel – so as to take maximum advantage of different water levels as they shifted from time to time.

The undershot wheel also was strikingly improved in the early nineteenth century, especially in France, where conscious use was made of Carnot's energy principle. In the Poncelet wheel (Figure 57), the flat floats of the old undershot wheel were replaced by specially designed curved vanes, which may have been suggested by the improved curved buckets of overshot wheels; and the water was directed to meet them at a tangent so as to produce a minimum of impact. Thus the water had a twofold effect on the vanes: it exerted pressure when it was deflected by the curve of the vane as it rushed into the bucket space, and it gave the wheel a second push as it returned down the vane to be dropped, practically without onward velocity, into the tail race. The buckets were never completely filled with water. The wheel could be very light, since it was subjected to little strain, and it could be made to rotate up to twice as fast as ordinary wheels. Well-constructed Poncelet wheels delivered an effect equal to about 55 per cent of the velocity of the current – a figure not far under that obtained from good overshot wheels. They were adapted, however, only to quite low falls, since for technical reasons the interior height of the buckets had to be at least one-quarter the head of water used to drive the wheel.

It is important to understand the action of the water in a Poncelet wheel, for it brings us to the threshold of great developments in hydraulics. The water acts both by impulse, in the direction of its motion, as it enters the wheel; and by reaction, in a direction opposite to its motion, as it leaves the wheel. The reaction effect will be familiar to anyone who has felt the kick of a gun: in any such release of energy, mass times velocity is identical in the two directions. This is the principle used in rocket guns and in jet propulsion; it is a principle that was first explored in windmill design, as we shall see; and this principle, thoroughly understood and scientifically applied, is responsible for the high-efficiency turbines that power our enormous hydroelectric plants today.

Figure 57 shows how, from the end of the fifteenth century, the reaction-turbine principles worked out tentatively in connection with windmill sails were adapted to direct-drive water wheels, which were equipped with slanted or even curved vanes, and moved by a crude combination of impact and reaction. A nearer approach to a true turbine was illustrated

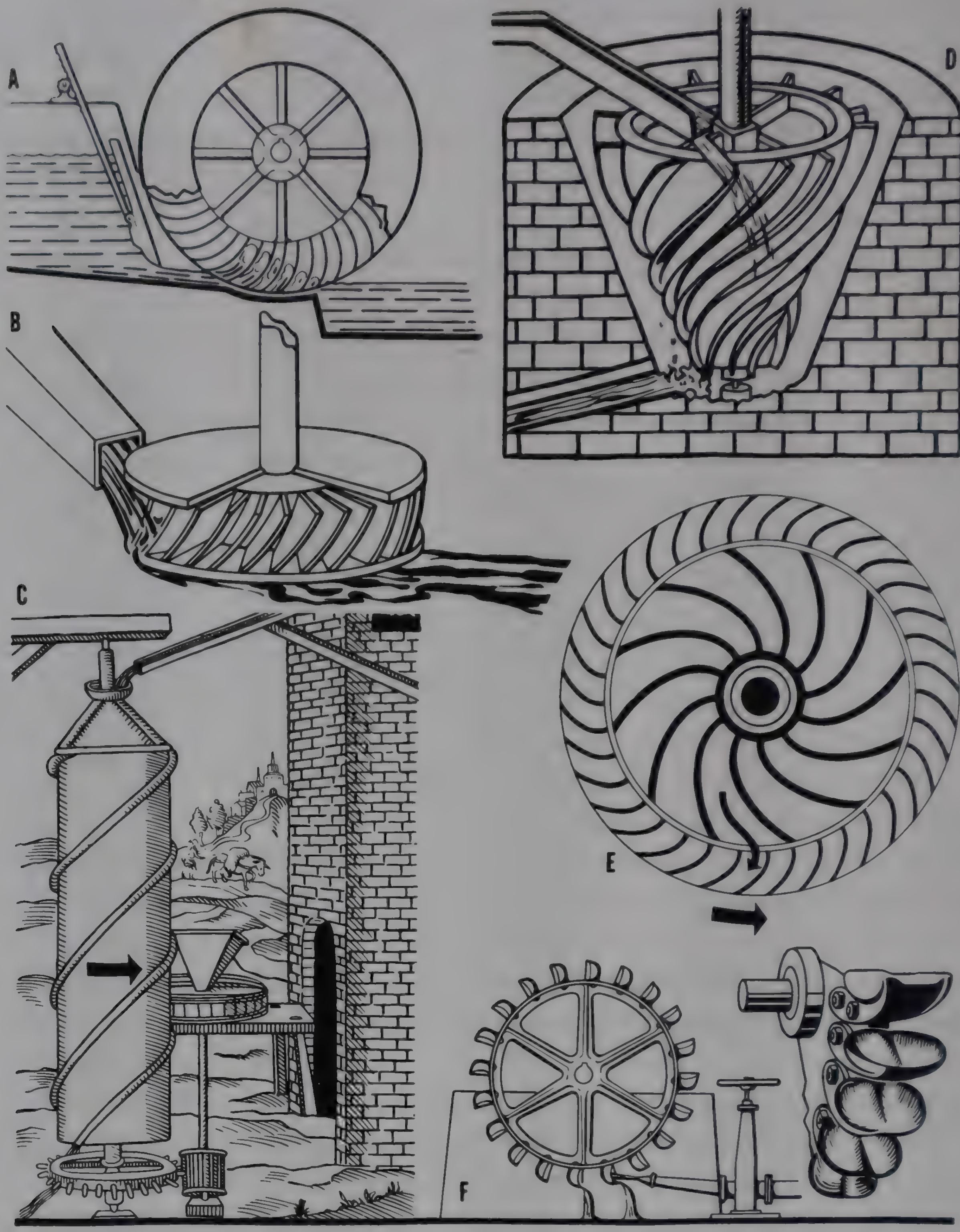


Figure 57. Steps toward the modern turbine. A, Poncelet wheel (1824), with specially curved buckets on the rear surface of which the water acts by impulse and reaction, as described in the text. B, direct-drive water wheel with curved floats, in use toward the end of the fifteenth century. C, Branca's 1629 design for a reaction turbine. D, eighteenth-century tub mill, similar to Besson's 1578 design. E, Fourneyron's 1827 turbine, which proved 85 per cent efficient. This plan view of the wheel indicates how the water is given direction by the fixed inner wheel, with its heavy guide vanes, and made to rotate the outer wheel by a planned combination of impulse and reaction. F, Pelton wheel, in which a high-velocity jet of water hits the ridge between paired buckets on a wheel, shown at the right, and gains in power thereby. Developed for use in gold mining by Lester A. Pelton, a millwright, in 1877–1878, this wheel revolved too fast for use in flour milling, but marked an important advance in hydraulics.

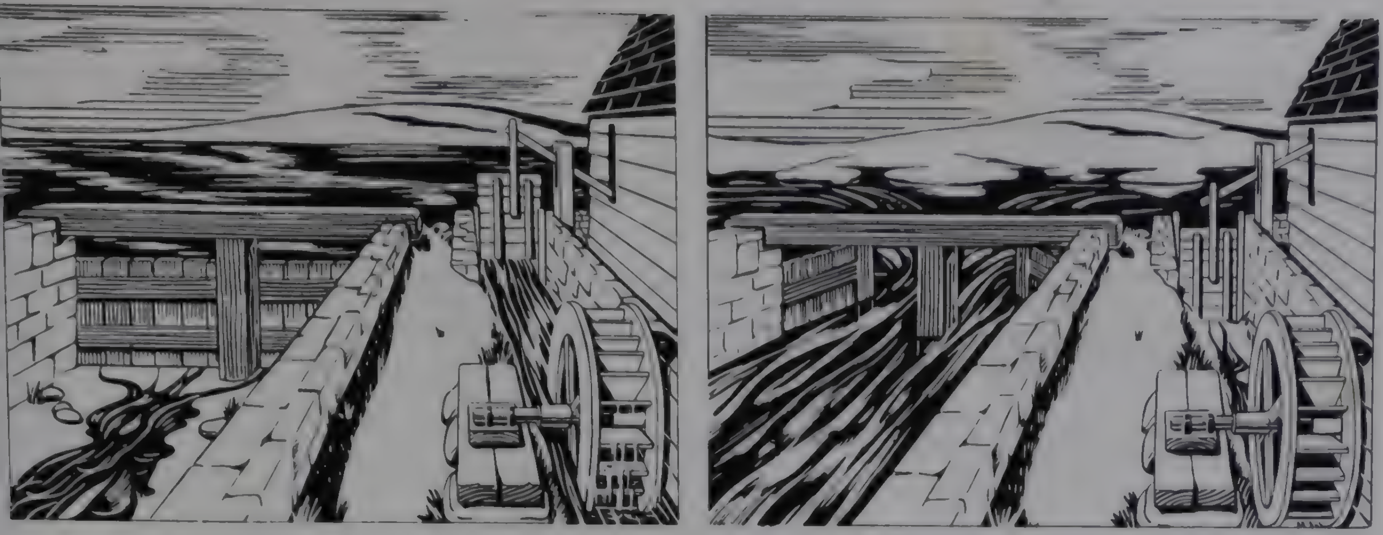


Figure 58. Tide mill. At the left, the sluice gate is closed and the millrace gate is open, with the water wheel in action. At the right, the incoming tide has opened the sluice gate to fill the pond; the millrace gate has been closed, and the mill is inactive. Milling can be carried on in two periods of five to seven hours each for every twenty-four hours.

in Branca's *Le Machine* of 1629. This was a dream-gadget in which a large cylinder was to be rotated by reaction to the water, as in our common revolving lawn sprinkler. But the weight of the cylinder and the friction of its bearings would prevent the device from doing much useful work. Nevertheless it represented a step forward in the understanding of the forces involved in moving water and how they might be utilized.

A tub mill illustrated by Besson as early as 1578 was more helpful to later engineers in visualizing some of the relationships that would obtain in a properly designed turbine drive. The spiral fins of this cone resembled Branca's spiral tubes, but action rather than reaction turned the cone: at the bottom the water was delivered straight down, without reactive force, and motion was due to the impact and weight of the water on the sloping fins. Belidor in 1737 described tub mills as well as other water wheels at le Basacle which lay horizontally like large ventilating fans at the bottom of water-filled pits. There was considerable energy loss as the water forced its way into these wheels and was literally thrown out, but they were nevertheless a further step in the direction of the turbine.

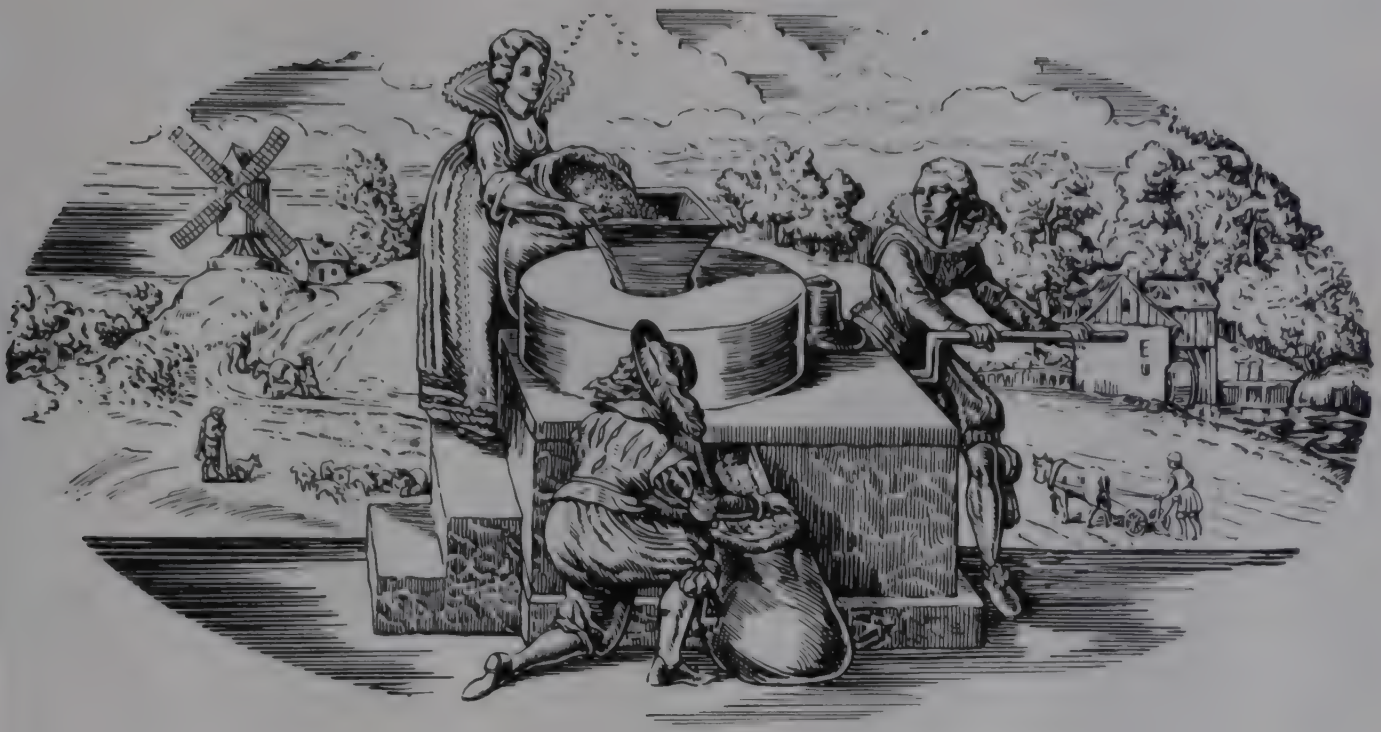
By a superb intellectual leap from the springboard of these and a few other devices, Fourneyron in 1827 separated the various elements in the water-power problem and recombined them in a novel manner to create the first really efficient turbine. By locating guide vanes on a stationary, horizontal cylinder set inside a small wheel with vanes like Poncelet's, he was able to immerse both cylinders completely, like the constructions at le Basacle, and direct the entire head of a body of water through the stationary guide vanes to act with maximum force on the vanes of the rotating power wheel. By comparison all previous water wheels were hit-

or-miss affairs: in Fourneyron's turbine the water rotated the wheel by impulse on entering and reaction on leaving, with minimal losses, in accordance with Carnot's principle, exactly as in Poncelet's invention of a few years before but throughout the entire circumference of the wheel. Fourneyron's first wheel was 87 per cent efficient — a very successful result even today. The improvement of turbines and the invention of new types have continued progressively since Fourneyron. Most turbine wheels rotate far too rapidly to be used directly for milling, but they are used in our modern hydroelectric plants to generate electricity for all kinds of manufacturing operations, including milling, and their prototypes were developed in the millwright's efforts to improve his water wheel.

Before we go on to the wind-powered mill and the special technical problems it posed, two subordinate varieties of water mill deserve mention, although they stand outside the genealogy of modern milling. Both were normally undershot. The floating mill was built on a barge moored in a stream, with the wheel of such a size that the current turned it at the desired speed. Procopius tells us that floating mills were devised by Belisarius in A.D. 536, when the siege of Rome by the Goths under Vitiges cut off the water supply from the mills on the Janiculum Hill. Such mills differ from other undershot mills only in location.

Tide mills are unique only in that their water reservoir is filled by the rising tide. They appear to have made their appearance about the tenth century A.D.; there is reason for believing that one was listed in the late eleventh-century Domesday census. After a long period during which tide mills were little used, they underwent a small renaissance in the eighteenth century, when several learned societies offered prizes for satisfactory designs. The ordinary type is shown in Figure 58.

In some tide mills the sluice is arranged so that the water wheel may be run first as a breast wheel and later as an undershot wheel. In more complicated types, the incoming water runs the mill for a period, with the water gate closed. Then the mill is shut down, the water gate opened, and the storage pond filled. After high tide the gate is closed again and another water wheel, or the same one geared to run in reverse, goes into action. Or by using two storage ponds in combination, a mill can be run continuously, although at a lower head than if it ran only after each high tide.



CHAPTER IX

Man Masters the Winds for Milling

> It required nearly as much courage to handle a large windmill as to handle a ship.
>
> —Bennett and Elton

> The millwright had anticipated ball and roller bearings, greatly developed gearing, and had applied, if not invented, the centrifugal governor.
>
> —E. Lancaster Burne

As the Roman Empire slowly crumbled, and its institutions of slavery and paternalism declined, new centers of production and trade grew up among freer men in what had once been barbarian hinterlands—first in the Frankish regions of Gaul, and later in central and northern Italy. Invariably these inland cities were located at sources of water power. With the passing of the centuries water mills became the bases of commercial prosperity, and regions without streams suitable for mills were at an economic disadvantage. It became a matter of life or death for them to

Chapter head oval. Fanciful eighteenth-century scene, "The Pleasures of Milling." Real labor, in field and in mill, is found in the background, while gentlefolk amuse themselves with hand grinding.

discover some other nonorganic source of power if they were to gain a place in the sun of the new world.

This situation was especially acute in the lowlands of Europe: they were fertile, all too well watered, admirably located for trade by land, sea, and inland waterways with all the civilized regions of western, central, and northern Europe, including the British Isles; but, being almost completely flat, they could not have water mills.

It happens, however, that these Low Countries are swept by the prevailing westerlies, winds that can be relied on to blow fairly steadily but not destructively. Once again the circumstances in which a people found themselves suggested the means of satisfying their social needs, and the Lowlanders developed the windmill into a power plant as effective as the water mill. It provided power for production and it operated pumps to drain the water-logged country, thereby becoming a decisive means of both reclaiming and maintaining the land. But to achieve these results a long series of new and subtle engineering problems had to be solved.

Air currents for many centuries had propelled ships on rivers and seas. But to sail a ship on water and to generate usable power at a fixed spot on land—engineeringwise these feats are miles apart. If water mills had not shown how a headlong, forward-moving force can be harnessed for useful work, the winds might never have been made a source of productive power.

The earliest records of windmills are a thousand years or more later than the first records of water mills: al Mas'udi and al Istakri, Arabian geographers who traveled widely through the Near East in the tenth century, found them in use on the banks of the Helmand in Seistan, in what is now eastern Iran. An oblique reference may indicate that Persia had windmills much earlier, before A.D. 644, but this is uncertain. The mills of Seistan were remarkably similar to the direct-drive or Norse water mill: like a water wheel submerged horizontally in a stream with the paddles on one side shielded from the current, the sails of these mills were set around a vertical shaft within a stone tower, built to let the wind rotate them in one direction (Figure 59). In both water mill and windmill, the wheel turned a millstone attached directly to its shaft.

It is obvious that such an immobile arrangement would be efficient only in a region of strong, unveering winds, and Seistan met this specification. Though the land today is "a swamp in the middle of a wilderness," before Tamerlane's invasion in the fourteenth century it was a remarkably fertile garden spot. This fertility was due to an irrigation system which Tamerlane destroyed in revenge for the laming injury he received there, a system that has never been rebuilt. Seistan has a constant wind, and with a vengeance—the hot *bad-i-sad-o-bist-roz*, or "wind of a hundred and twenty days," which howls unremittingly from an almost northerly direction throughout the summer. Winter winds, somewhat gentler and less

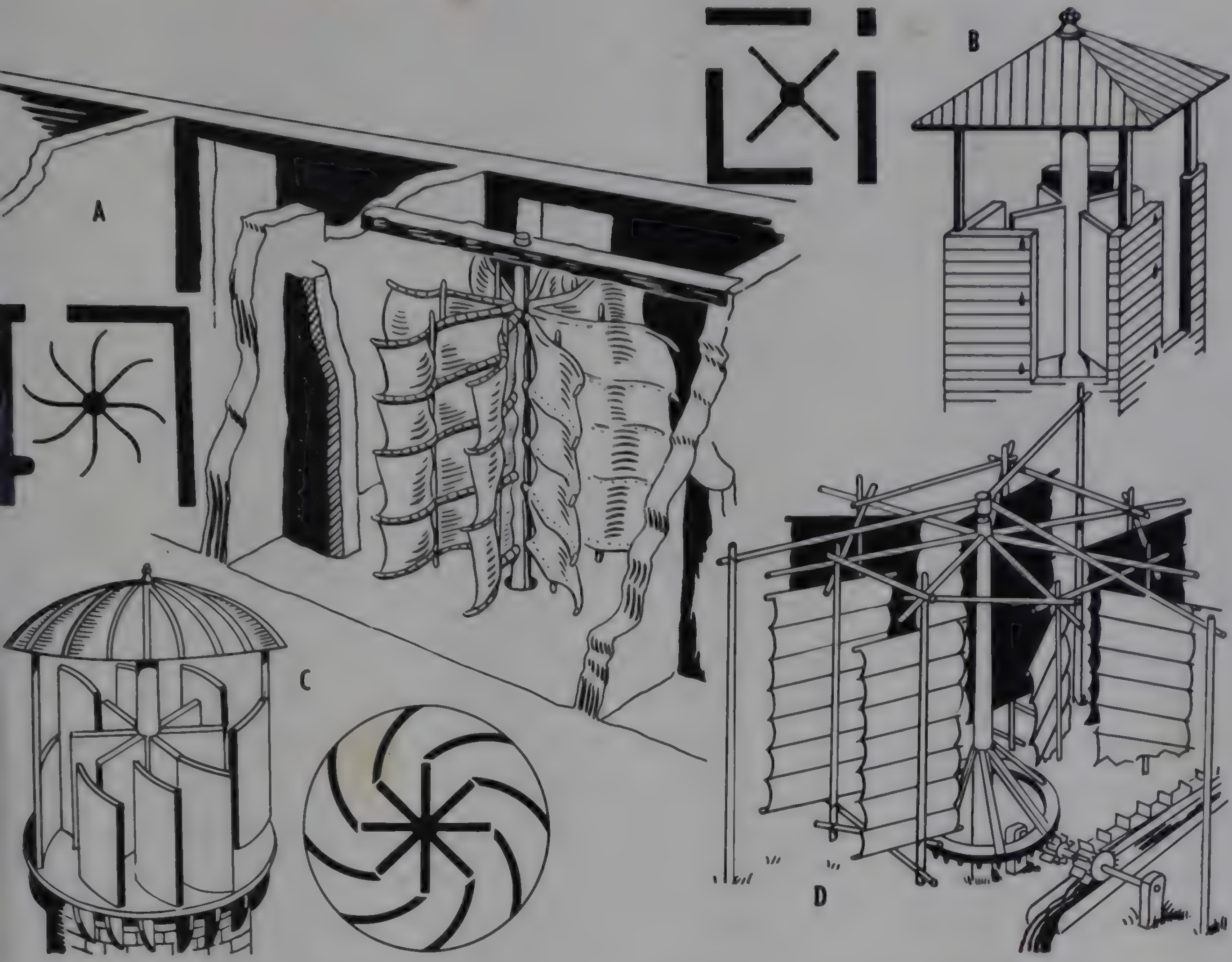


Figure 59. A, Persian-type direct-drive windmill on vertical axle, known from at least the tenth century A.D. B and C, Veranzio's early seventeenth-century Italian designs for direct-drive windmills. They could be driven by a wind from any direction, whereas the Persian type requires a wind of constant direction. With B, however, some winds would rotate the millstone in a reverse direction from others, if no gears were used. D, Chinese vertical-axle windmill with pivoted sails which will face a wind from any direction, used even today for raising water in salt-making.

persistent, blow from the same direction. These were perfect conditions for the tower-enclosed windmill. But the same kind of installation could be adapted to more variable winds in ways suggested in Figure 59.

There is so much similarity between the mechanics of direct-drive water mills and direct-drive windmills that it is easy to assume a link between the two; we are even told that the millstones used in Persia "are identical with those used by English millers – they are of the same shape and size." Contact between Europe and these regions of the Near East was maintained from the time of Alexander's occupation in the late fourth century B.C., and from the ninth to the eleventh centuries the Northmen were engaged in active trade across Russia with the regions of Khorasan and Kharism, immediately to the north of Seistan. The trade was brisk – over 100,000 Persian and Arabic coins have been found on the route through Russia and on into western Europe, 30,000 in Sweden alone. It is possible, though doubtful, that these Northmen carried to Seistan the direct-drive water mills which modern archeologists call by their name; it is more probable that they carried back from Seistan to Europe the idea of harnessing the winds for useful work. At the same time that the Northmen were traveling to the borders of Seistan, they were well settled in the Netherlands — from the ninth century, and for some time thereafter — and must have been cognizant of its needs.

If this was the sequence of events, it was the idea of using wind power rather than the Persian mechanism that was transmitted to Europe. So far as is known, no direct-drive windmills were built in early days in the West, where, in spite of the prevailing westerlies, winds were not strong or constant enough to make them profitable; and even under the best conditions a direct-drive windmill is highly inefficient: it delivers no more than a quarter of the power delivered by a Western-type windmill with sails of equal length. The reason for this is, of course, that in the direct-drive mill the wind exerts its force against only a fraction of the sail area, and even exerts a drag against the sails immediately after they have passed the exit aperture of the enclosure; whereas in the Western mill the wind exerts its force against the entire sail area, employing very effectively the reaction principle of the turbine. Yet in later centuries there were frequent experiments with the horizontally rotating sail design, and in modern times Flettner has constructed in his rotor a horizontal wind engine of high efficiency, but operating on very different principles.

When, how, and by whom the Western, vertical-sailed windmill was invented are among the many important facts of technological history not recorded by an indifferent past. All the early European mills we know about were of this type. In spite of the lack of direct evidence it is fairly certain that windmills were built in the West before the end of the eleventh century. A twelfth-century grant of land in London for the erection of a windmill, described in a seventeenth-century account, is referred by modern scholars to about 1145; and there is an authoritative record of a windmill at Bury St. Edmunds, England, which was ordered pulled down in 1191 because it had been illegally erected. Domesday Survey, the 1086 inventory of real property in England, may include windmills, but this cannot be proved. In succeeding centuries they were mentioned with increasing frequency, but it is not until 1557, in Cardan's *De rerum varietate*, that we find an analysis of windmill action, and by that time they dotted the Low Countries by the thousands and were known all over the civilized world.

The developed Western windmill embodied a number of radical departures from water-mill design, and an astonishing number of new inventions, many of them based on newly discovered mechanical principles. Basic in their construction are, first, the turbine-type sail wheel which must

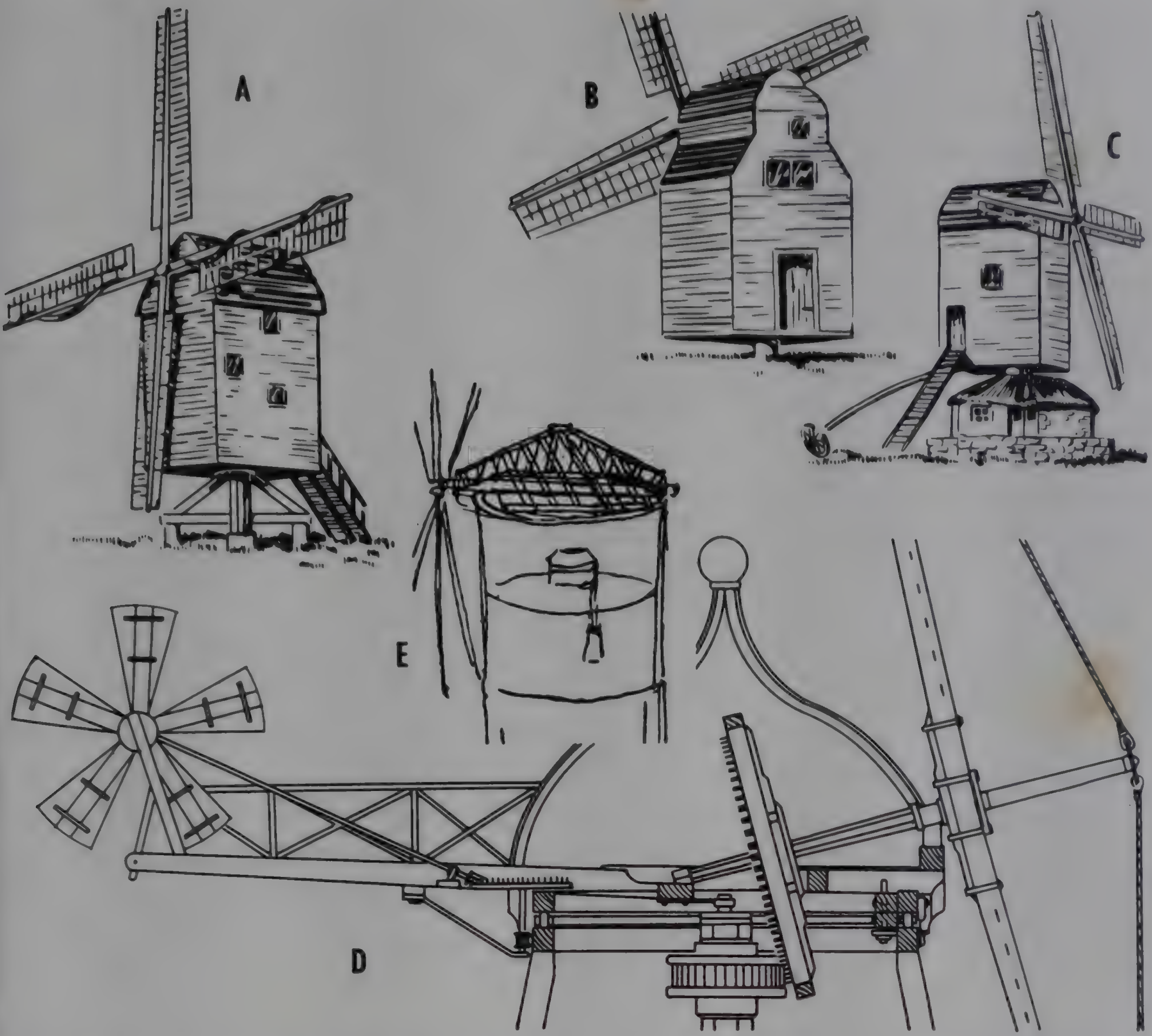


Figure 60. Windmill types. A, post mill, resting on a column supported by bracing beams. B, sunken post mill. C, post mill with storage room around the center post. D, cap mill showing bearing ring for the cap and arrangement for gearing the fantail. E, Leonardo's sketch for a cap mill.

turn in a plane at a right angle to the wind; second, a means of shifting either the entire mill or the power drive alone so that the sail wheel can face the wind no matter whence it blows; and, third, some means of maintaining a fairly constant rate of work-speed no matter how the velocity of the wind may vary. None of these features, except in some instances a method of braking, were anticipated in the water mill: turbine water wheels were not in use until the eighteenth century, as we have seen; water could be stored and fed to water wheels at an unvarying rate, and always from the same direction, but even "prevailing" air currents at any given spot in Europe may veer around the compass and vary in force from nothing at all to gale intensity. Another variation from water-mill precedent was the fact that the power drive was now normally above the millstones — overdrift or "quant drive" — instead of below — underdrift or "damsel drive" – different methods of tentering the runner stone and somewhat different methods of feeding thus being called for.

Because of all these unique problems, the windmill was responsible for a second notable spurt of progress in the mechanical arts. And since the windmill is an aerodynamic engine, its builders gradually discovered and applied in a crude way – without fully understanding them – some of the aerodynamic laws which were not thoroughly explored until the modern airplane gave them crucial importance.

The earliest type of geared windmill is the post mill (Figure 60), in which everything – sails, shafts, gearing, millstones, housing, and contents, including the miller and his helper, if any – is supported by a heavy horizontal beam called the crown tree, and pivoted on a single stout central post set in the ground. Mark Twain came upon mills of this kind still in use in the Azores: "Small windmills grind the corn, ten bushels a day, and there is one assistant superintendent to feed the mill, and a general superintendent to stand by and keep him from going to sleep. When the wind changes they hitch on some donkeys and actually turn the whole upper half of the mill around until the sails are in a proper position, instead of fixing the concern so that the sails could be moved instead of the mill."

This was a nineteenth-century survival, more than five hundred years later than the early and simpler example drawn by an unknown artist in 1349 (Figure 61). Here we see the "tail pole" by which the mill was turned projecting through the ladder. When it was necessary to shift the mill, the

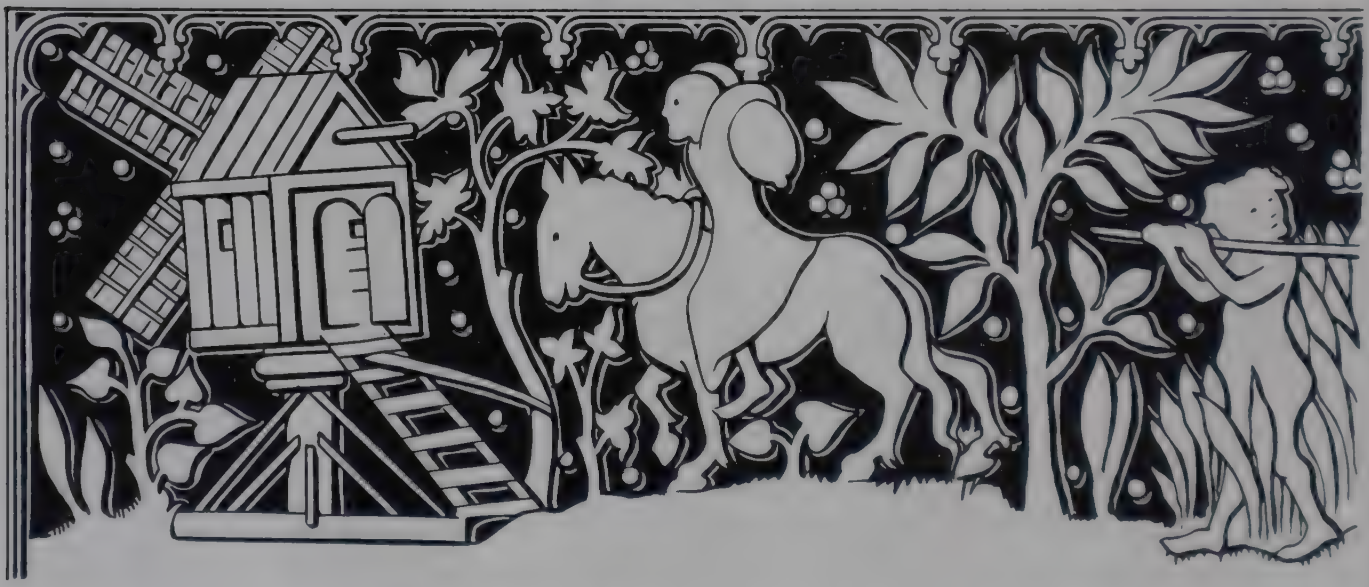


Figure 61. Earliest known depiction of a windmill, of post-mill type, from the Walsokne brass at Lynn, Norfolk, dating from 1349. A man on horseback is bringing a sack of grain to be ground, carrying it on his shoulder to ease his horse of the burden, as Waller remarks. The bird-house size of the mill should not be taken literally: it may indicate that the mill was still at a distance, or with the customary license of early draftsmen, the artist may have reduced its size to get it all into the design. The doorway provides a scale indicating that the structure was much larger than it appears.

steps were either separately lifted or levered up by the tail pole; later when steps had become heavier, a "talthur," or lever attached to the tail pole, raised the steps while turning.

The cant of the Walsokne structure indicates the precarious balance of a post mill, perched on its pivot, and weighed down on one side by its great sails. It had to be built to ride the winds very much like a ship, steered by its tail pole, and with its weight carefully distributed. "When the miller stands a sack of grain on one side of the mill he stands another on the other side, to keep her in trim." This was such a structure as could easily have been devised by those hardy seamen, the Northmen, or by those other intrepid navigators, the Arabs.

The first supports of post mills probably were great tree stumps, but the center post on which the Walsokne mill rested was a shaped column held upright by bracing beams. From an early date, however, the center post was buried in the ground with only its top protruding, so that the mill rested flat on the surface or on a mound built up around the post (Figure 60). This was a more stable placement, and the mill could be made larger since it was less likely to be blown over in a gale. Already in the Laws of Oleron, that twelfth-century code of maritime law which was adopted in England about 1314, this type of mill is mentioned: "Some windmills are altogether held above the ground, and have a high ladder; some have their foot fixed in the ground, being, as people say, well-affixed."

Another early variation was to build a walled room around a high center post, giving the mill proper greater stability and providing space for storage and for holding such accessories as bolters for sifting the meal. This appears to have been the type that Mark Twain found in the Azores. By making the walls of this space more substantial, it became possible to seat the pivot of the mill on crossbeams in the ceiling, so that the entire lower room was free for use. Then from about 1450, in the Dutch hollow post or turret post mill (*wip-molen*), power from the sails was carried down into the lower room by a shaft through the middle of the center post, and the millstones were moved to the ground level, materially decreasing the size of the rotating portion. A mill so built had to be very sturdily supported on its central shaft, as any sway might damage the vertical power shaft or the gearing below. In their new location the millstones could be driven either from above or, by additional gearing, from below. To drive them from above left more free space, and was more usual, but made it necessary to disassemble the vertical power shaft when removing the millstones for dressing.

In spite of its ingenuity, the hollow post mill was a makeshift which had to do until the invention of the cap mill, in which only the very top of the mill need be turned to face the sails into the wind. The basic structure of the Western-type geared windmill was now complete. It has been claimed that Lief Andries of Alkmaar constructed the first cap mill in 1573; but Leonardo da Vinci, who died in 1519, sketched one in a notebook, and there may have been mills of this kind on islands in the eastern Mediterranean far earlier than in Holland. Cap mills with triangular or jib sails (Figure 64) are said to be shown in a fifteenth century illustration as in use on the Island of Rhodes. The cap mill may have been invented independently in the north of Europe and somewhere in the Mediterranean area: it is the only old type of windmill to be found in Spain, and it occurred in southern France, but these cap mills were separated from those of England, Holland, and northern Europe by a wide belt in which post mills were built almost exclusively.

Leonardo's drawing omits a critical detail—the method of mounting the cap on the main structure. The cap must be held securely on its seat in spite of its being greatly overbalanced by the sail wheel, and it requires a circular bearing of large diameter. Maintaining balance had been serious enough in earlier mills, where the sail wheel had acted against the weight of the main body of the mill, plus stairs on the opposite side. The situation was improved somewhat by inclining the wind shaft so as to slant the whole sail wheel backward about 10°, thus moving the center of gravity of the wheel and wind shaft with its heavy brake wheel a little nearer to the center of the mill structure. Sometimes the balance was helped slightly by giving the cap of the mill a backward projection, or by adding, at the rear end of the wind shaft, a subsidiary gear wheel to run accessory apparatus. The long tail pole by which the cap was at first turned also added its weight. When the fantail device was finally extended out to the rear, the problem of sail balance was solved (Figure 60).

Early cap mills were still turned into the wind by a hand-shifted tail pole reaching to the ground, in the same manner as post mills. As the cap was built heavier, the pole sometimes was turned by a geared winch, worked against one of a circle of posts set around the base of the mill (Figure 62). The cap also could be turned by a winch or a lever from inside the mill; or by a pulley wheel and endless chain geared by a pinion to a rack on the main structure. Finally in 1750 Andrew Meikle invented the fantail—a small sail wheel placed in the rear at right angles to the main wheel so that it would rotate whenever it did not stand edge-on to the wind. This fantail was geared to a circular rack on the mill structure and would rotate the cap automatically until its wheel was again edge-on and the sail wheel faced into the eye of the wind. The winch and fantail were quickly adapted to the post mill after they came into use with cap mills.

Another critical problem was to provide a satisfactory bearing on which to rotate the cap. The cap and sails were too heavy to slide directly on the mill structure, and wheels made too precarious a connection between the

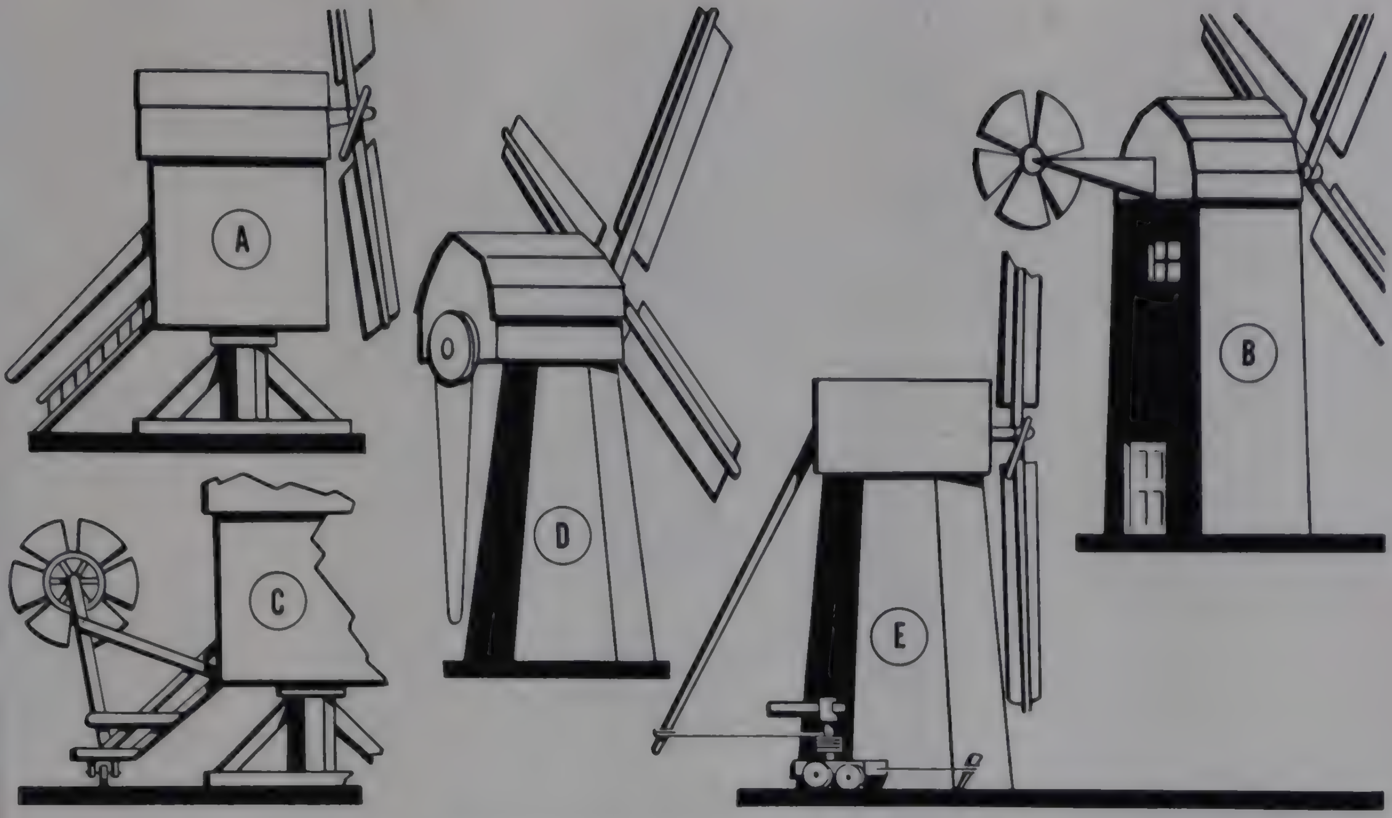


Figure 62. How windmills were turned into the eye of the wind. A, tail pole on a post mill – the earliest method. B, Meikle's fantail on a cap mill (1750) – the final solution. C, fantail attached to stairs of a post mill. D, pulley wheel and endless chain on a cap mill. E, winch used with tail pole on a cap mill.

two. The ideal solution was metal roller bearings held in a ring cage, so that the weight of the top would be distributed among many rollers and the top could not tip. We are told that the Dutch were using such bearings by the end of the eighteenth century. But only a little earlier there had not even been metal gears of any kind, and all gear teeth were cut laboriously by hand. In these circumstances the production of metal roller bearings adequate for a cap mill was a noteworthy achievement. The fine engineering which millwrights had achieved by this time is shown in the design adapted from van Zyl's famous book on the subject, dated 1761 (Figure 63).

Slanting the sail wheel backward yielded one or two advantages, in addition to improving the balance. The sides of the mill structure could be slanted outward, and upon this broader base a taller structure in a more stable conical form could safely be built, making room for a bigger sail wheel with greater power. Other conditions being equal, power varies as the square of the diameter of the wheel: a 30-foot wheel could deliver almost 50 per cent more power than a 25-foot wheel. Also with the slanting sail wheel and inward sloping mill walls, the winds created less turbulence at the base of the mill – an important aerodynamic consideration since the sail wheel is helped to rotate by flow conditions behind as well as in front of the sails.

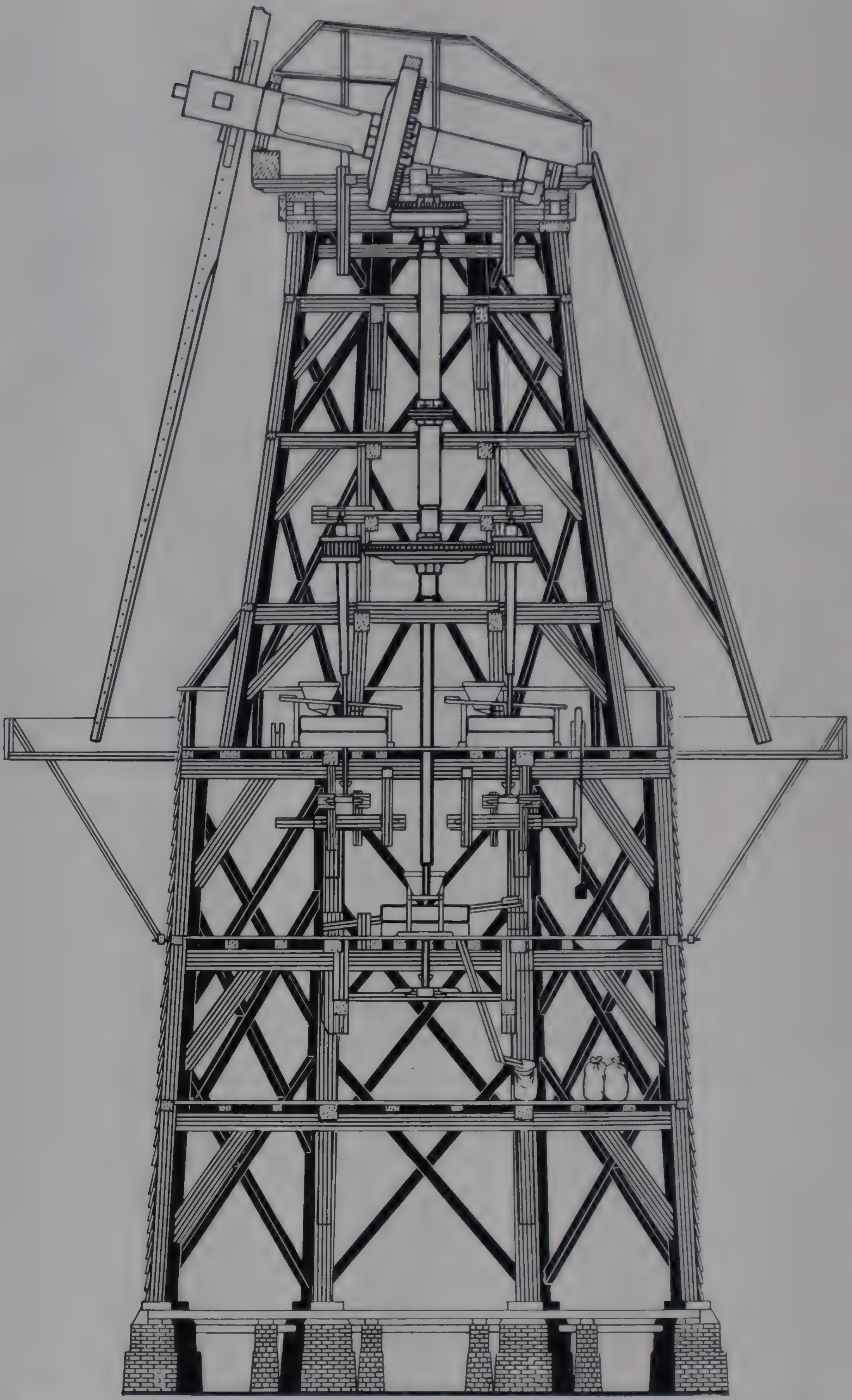


Figure 63. Construction details of a cap mill from van Zyl, *Theatrum machinarum universale* (1761). The principal moving parts, from the sails to the three run of millstones, are unshaded in our drawing. Note the roller bearings on which the cap of the mill rotates, just below the rear bearing of the great beam which holds the sails. This mill was rotated by a tail post. Note the complete absence of machinery for bolting, which must have been carried on elsewhere.

As the water wheel was the most difficult technical problem in water mills, so the sail wheel puzzled the designers of windmills for centuries. Both the structural and aerodynamic requirements for high efficiency were more elusive, and it is very creditable that such admirable results were attained in time through mere observation and experience, trial and error, without a very clear understanding of the principles involved.

In all Western-type windmills the sails radiate from the wind shaft, and their "whips" are mortised into its hub. Two sails were usually sufficient to run a mill, especially after it had started, although not without vibration; four was the usual number, giving smoother action, but sometimes there were six or even eight. The mortise for each additional whip weakened a wooden hub by just so much, a critical difficulty which could not be overcome until iron came into use for hubs late in windmill history.

The seriousness of these structural problems will be appreciated when it is realized that the sail wheel of an early mill was perhaps 30 feet in diameter, but that wheels of 60 feet or more eventually became common; the mills of Great Yarmouth, in Norfolk, England, had a sweep of 100 feet. The sails usually were rectangular, with a length about five times their width and a total area which seldom exceeded about one fourth the area covered by the wheel in rotating.

A windmill sail was "feathered"—turned somewhat on its own axis. This "angle of weather" was the secret of its power: the wind pushing against the slanting surface acted to rotate it in the direction of its leading edge—the edge, that is, most advanced toward the wind. Thus the windmill sail wheel became the first power mechanism to be activated by reaction alone.

At first the sails were made of strong cloth woven back and forth through crosspieces set a foot or so apart, so that they might be furled for a strong wind, and were centered on their whips or supports, with the same amount of cloth on either side of the whip—the so-called "double sweep" (Figure 64). Somewhere on the Continent, at an indeterminate date, perhaps toward the end of the fifteenth century, the double-sweep began to give way to the single-sweep sail, in which about four fifths of the sail area lies on the trailing side of the whip. This was an important innovation, revealing a better practical understanding of aerodynamics. We now know that a windmill sail when rotating does not balance along a line passing from the axle through its static center of gravity; the center of pressure equilibrium is farther forward, toward the leading edge. Thus the change in position of the whip put the sails in better running balance.

But there was more to the change than this: though the whip may have been advanced in the first instance so that its projecting shape would turn the wind onto the sails and thus keep them from fluttering, as Burne suggests, the new position gave what the millwright came with great insight

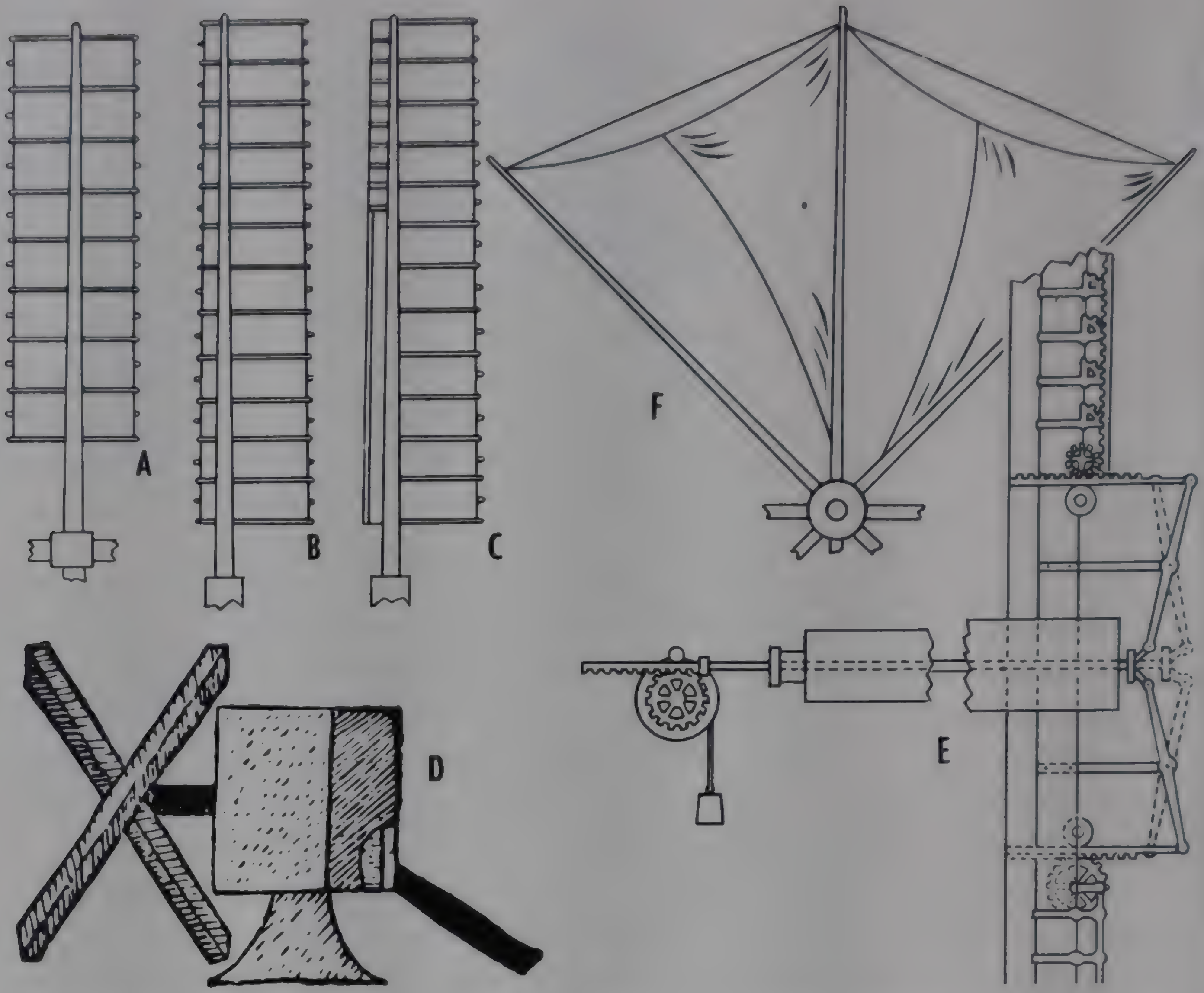


Figure 64. Windmill sail types. A, early double-sweep sail, with whip running down the center. B, single-sweep sail, with whip advanced toward the leading edge, the edge which first meets the wind. C, sail with leading board. D, Cardan's diagram to illustrate windmill action; from *De rerum varietate* (1557). E, Cubbitt's patent sail (1807), with alternative forms of action illustrated on the top and bottom sails. F, jib sail occasionally found on windmills in the Mediterranean.

to call a "pull" to the wheel. The millwrights were talking about what the airplane designer calls "lift." By dipping the lower front edge of an airplane wing somewhat, rounding the upper front edge, the airplane designer takes full advantage of air flow past the wing: a push or lift on one side of the wing in flight is supplemented by a still greater pull or suction on the other side. The effect is at a right angle to the direction of air flow—upward in a properly designed airplane wing, at a tangent to the plane of the sail wheel and in the direction of the leading edge of each sail at all times in the case of a properly designed windmill. The whip toward the leading edge of the sail "dipped" that edge outward, toward the oncoming wind, and increased the "lift" of the sails.

But the projecting whip was not especially well shaped for this purpose. It was not long, apparently, before it was supplemented by a slanted leading board specifically designed to take advantage of the "lift" phenomenon. It is exactly a post mill with sails of this kind that Cardan diagrams and describes in his *De rerum varietate*, which was published in 1557, where he calls it "a thing which is so wonderful that I could not believe it" (Figure 64). We can be sure that he was not surprised by the mere existence of windmills, as Bennett and Elton believe – he must have seen hundreds of ordinary mills in his travels – but by the great power of these particular mills: "There are now in parts of Italy and France, in many places, windmills which are turned by the wind, and with such force that they could carry round three horsemen, horses and all, and they are so effective that they can grind three thousand pounds of grain per hour."

Cardan's description of the triangular cross section of the sails that astonished him follows: "Each sail consists of two surfaces. . . . The upper surface looks back a little, while the other surface is equidistant from the rear surface of the machine. . . . If the upper surface were erected perpendicularly . . . the wheel would meet with as much resistance from the upper sail as there was force exerted by the lower."

What Cardan is struggling to explain is the "lift" or "pull" of the sail at a right angle to wind direction. A similar explanation given by Bacon in his *Historia ventorum* (1622) is quoted disparagingly by Bennett and Elton who, writing in a pre-airplane period, nowhere give any indication of understanding the action of windmill sails.

Bacon's suggestion that the width of the sails should be increased toward the circumference of the sail wheel was excellent, but his advice was not heeded – millwrights were not in the habit of reading philosophers. In papers read before the Society of Arts in 1759, Smeaton, who did such excellent research on water-mill design, recommended the addition of a triangular section to the leading edge of the sail, its width at the circumference of the sail wheel to be three fifths the width of the rest of the sail surface. In the same papers he also reported on the best angle of weather for sails. For a running mill the angle should start at 18° near the center of the wheel, and should diminish to 7° at the circumference. An ideal sail surface would be concave to the wind: "When the wind falls upon a concave surface, it is an advantage to the power of the whole, though every part, taken separately, should not be disposed to the best advantage." The Dutch millwrights in some instances had turned the tips of their sails well forward, with a view to preventing the cloth from flapping outward when the sweep passed the mill housing, where turbulence was greatest. Cloth-rigged sails with a variable angle of weather from the center to the circumference became so usual in England that they were called the common sail.

Ordinary cloth-rigged sails of whatever type could be made to rotate more slowly in a high wind only by reefing them with knots, exactly like a ship's sail; the alternative of turning the wheel out of the eye of the wind

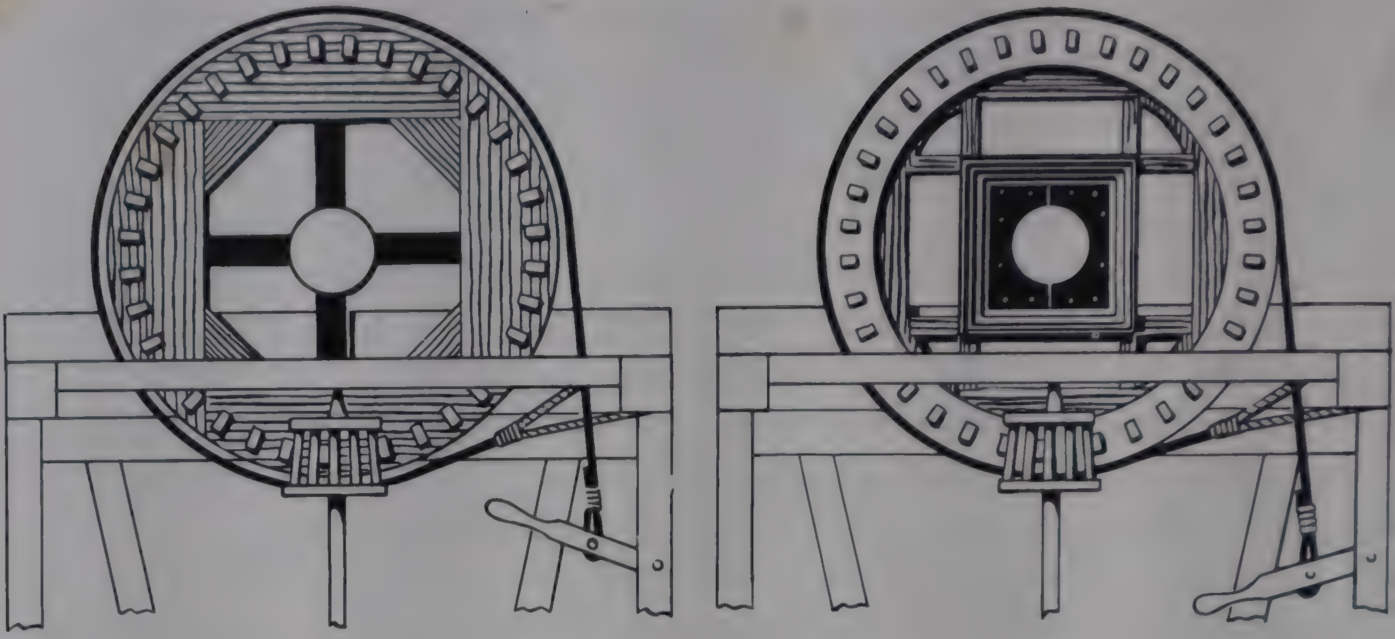


Figure 65. Types of brake wheel. At left, the compass-arm construction, in which crosspieces pass through the wind shaft. At right, the clasp-arm construction, in which the shaft is boxed to receive the spur wheel. The latter construction is by far the stronger. The brake band is shown released at the left, and applied at the right. The lantern gear on the main drive shaft in mesh with the brake wheel was known as the "wallower."

threw the mill out of balance. For reefing, the mill had to be stopped successively with each sweep near the ground so that enough of the sail could be rolled up to permit grinding to continue – a laborious and sometimes dangerous operation. In 1772 Andrew Meikle patented his spring sail, in which the sails on each sweep were made of shutters somewhat like those of a Venetian blind. The shutters swung open, against the resistance of a spring, to spill the wind when it reached a certain velocity. To change the setting of the spring each sweep had to be adjusted separately, with the mill at rest and the end of the sweep near the ground. Finally in 1807 William Cubbitt brought out his patent sail (Figure 64), in which a similar spilling device was geared back into the mill by means of a rod passing through the center of the wind shaft and made to work forward or backward against the resistance offered by a weight, which could be adjusted to any desired tension without stopping the mill.

Cubbitt's invention accomplished a considerable gain in convenience, along with one or two disadvantages. The outside parts had to be kept well lubricated, or they would not work satisfactorily. Also patent sweeps did not close so readily as spring levers and couplings, so that less power was developed on a gusty day. A good many English mills were run with one pair of patent sails and one pair of common. So far as other countries were concerned, the English inventions were never generally accepted.

The speed of grinding in early windmills could be reduced only by the dangerous recourse of turning the sails out of the eye of the wind and risking the destruction of the mill in winds of gale intensity. From about the fifteenth or sixteenth century, according to Usher, rotation was slowed down or stopped by moving a lever to apply a brake band to the brake wheel, in very much the same manner as an automobile is braked today. The brake wheel was also the main drive gear on the wind shaft, and meshed with the "wallower" gear (Figure 65) on the vertical drive shaft which transmitted power to the stones below. Until the late sixteenth century the brake wheel, like all other principal mill parts, was made of wood, and in braking there was very real danger of fire if the wood became overheated. In fact, most mills eventually either burned down or were blown down.

The massiveness of windmill construction will be appreciated when it is realized that brake wheels in the seventeenth and early eighteenth centuries might be as much as 11 feet in diameter and a foot or more thick, with nearly the whole of the space completely filled with heavy wood. Early brake wheels were of compass-arm construction: the wheel was built on two wooden crosspieces which passed through the wind shaft (Figure 65). This so weakened the shaft that a clasp-arm wheel was devised, in which the wind shaft is squared to receive four segmental pieces to hold the rest of the wheel. Clasp-arm wheels could be removed without disassembling the wind shaft, and did not so seriously impair its strength.

Sail wheels were planned to rotate, usually in a counterclockwise direction, about twelve to sixteen times per minute with an average wind, and the gear ratios were such that the runner stone rotated about ten or twelve times as fast. But the speed of rotation of the sail wheel, braking aside, was at the mercy of the wind. Finch gives the following table of wind velocities and resultant windmill action:

Wind Velocity	*Type of Wind*	*Action of Windmill*
10 mph	.........Fresh breeze	Will run slowly
15 mph	.........Good wind	Will run steadily
20 mph	.........Strong wind	Gives best service
25 mph	.........Very strong	Maximum useful effect
30 mph	.........Gale	Sails partly furled
40 mph	.........Storm	Must be put out of action

In most locations a windmill could be counted on to run about eight hours in every twenty-four; but periods of usable wind were as likely to come by night as by day, and the miller had to use his wind when he had it. A well-constructed windmill with a sail wheel whose diameter was 30 feet would deliver about one horsepower in a ten-mile wind. In mills with similar sails power would increase, within narrow limits, not only as the square of the sail wheel's radius but as the cube of the velocity of the wind.

By the beginning of the sixteenth century, metal was commonly used for many small parts, and long metal strips were sometimes inserted lengthwise into the bearing ends of shafts, such as the wind shaft. It was not until 1769 that cast-iron gearing was first sparingly used, by Smeaton, and not until 1784, in Watts' Albion Mill, the first powered directly by steam, that cast iron was used for all gears and shafts, by James Rennie.

With respect to mill gears generally, we have already mentioned the difficulty of cutting wooden gear teeth by hand. Toward the middle of the eighteenth century Brindley invented machinery for cutting gear wheels, and in 1752 Camus worked out the properties of the epicycloid curves that for long were used for gear teeth, and established the principles of construction of bevel gears. A little later it became possible to construct gears based on involute curves, which have the property of working just as well after the teeth have worn down — but not broken off — as at first, and which under certain conditions can be made interchangeable, so that a new standard gear of a different size can replace one formerly used. As bevel gears were improved and came into more common use in the eighteenth century it became possible to set up a large number of millstone pairs in a straight line, powered off one shaft, instead of arranging a few stones around a large spur wheel. This made it easier to group different processes — cleaning, grinding, bolting, sacking — giving a better integrated mill.

The distance between the millstones could be regulated, or tentered, in the case of underdrift stones by having the stone spindle rest on a lever bar which could be moved to raise or lower the runner stone, in exactly the same manner as in water mills (Figure 51). With overdrift stones the quant could be raised or lowered. But with millstones rotating rapidly in a brisk wind, continuous automatic adjustment was also needed, since the upper stone tended to ride higher as its speed of rotation increased. To solve this problem the centrifugal governor was adopted. Originally invented by Huygens in the middle of the seventeenth century to regulate clocks, it was used in mills — its first use with heavy machinery — certainly by 1787 and 1789, when patents for it were taken out by Thomas Mead and by Stephen Hooper. As the drive shaft rotated more rapidly with an increase in wind velocity, centrifugal force threw the balls of the governor more widely apart, causing a combination of levers to force the runner stone down. With a decrease in wind velocity the balls swung less widely and exerted less pressure on the runner stone.

For an example of the special conditions governing windmill design, consider Hills' explanation of the differences between mills in Sussex and in Essex. On the Sussex downs there is an abundance of wind, so that the sails there could not safely be as long as those in Essex, and the wind shaft could enter the mill at a lower elevation, making it possible to drive the runner stone from beneath. This meant that the sails could not be tilted as far back as those of Essex; in order to clear the mill housing, the Sussex millwright curved the end of his sails outward like those on many Dutch mills. Sussex mills could hardly do without patent sails, which were safer in a tempest, while Essex mills used cloth sails so as not to lose their small winds.

That well-designed mills were extraordinarily profitable even in early days is shown by a fourteenth-century English document in which pasture land rented at three pence an acre per year, a farm with barns and cattle pens at five shillings, and a windmill at fifteen shillings, the equivalent of sixty acres of pasture land. Yet this was at a time when the windmill had undergone but few of the changes we have described; the mill in question can hardly have been other than a small hand-turned post mill, with a small sail wheel driving at most two pairs of stones.

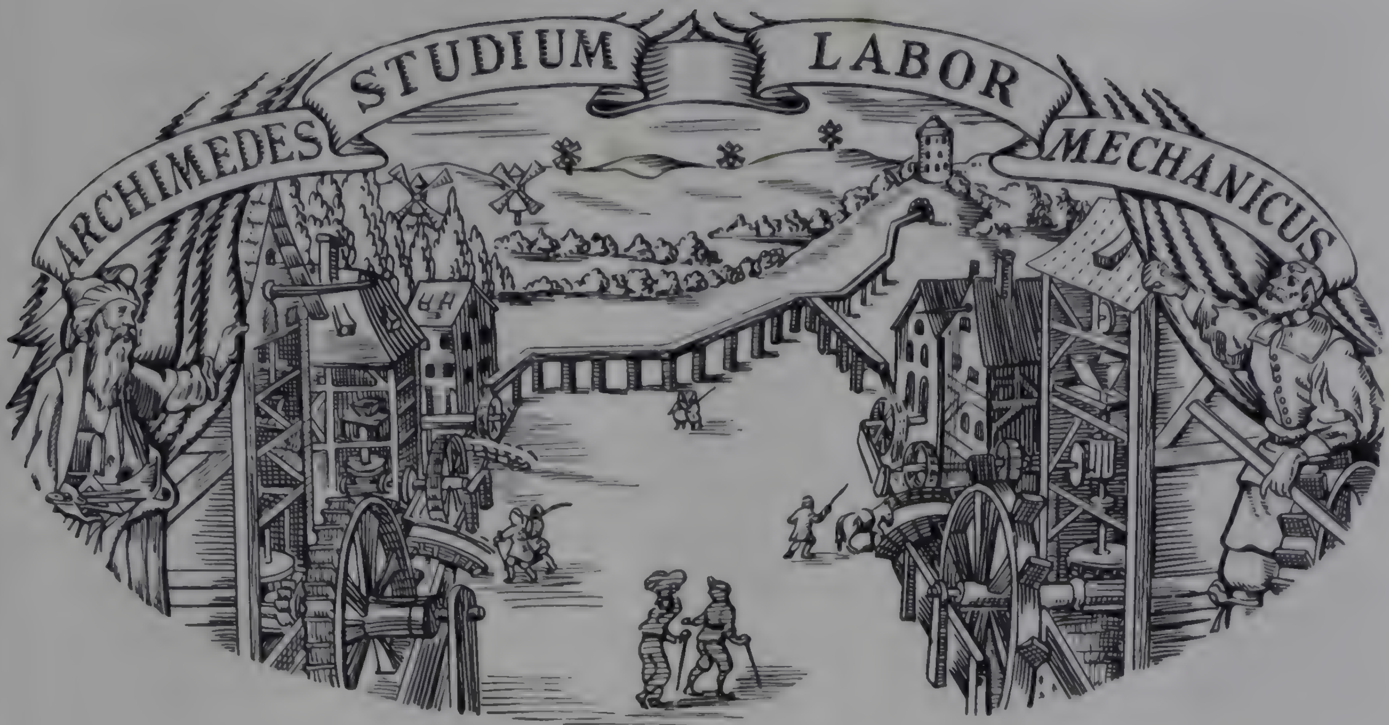
An ordinary post mill with a sail wheel from 50 to 60 feet in diameter could grind about 6 bushels of wheat (360 lbs.) in an hour with one pair of stones in an ordinary breeze of, say, ten miles per hour. A tower mill with a 75-foot sail wheel could grind about 8 bushels (480 lbs.) per pair of stones in a similar breeze. The post mill might drive two pairs of stones, doubling the result; while the tower mill might drive four pairs, quadrupling its figure. With a stronger wind both outputs might be doubled. The large windmills of Norfolk, England, with their 100-foot sail wheels, drove six pairs of stones to grind 40 bushels (2,400 lbs.) of grain per hour in a moderate breeze, and twice as much in a stronger wind. The power that did all this work cost nothing whatever, of course.

Why, then, are not windmills still scattered all over our landscape? Finch made a study of the rise and decline of windmills in the English county of Kent, showing that the number rose steadily from 1596 to the first half of the nineteenth century, when there were 239 in operation. Since then the drop has been swift, until only 16 were left in 1930. This curve is typical of many regions. The reason for the decline is the intermittence of wind power. This can be ignored in small installations intended for local use, but in large mills the far greater investment, the huge supplies of grain that must be handled, and the ceaseless demands of the flour market make continuous operation an economic necessity. As the steam engine was improved into a reliable machine, it was inevitable that it and the later prime movers that stemmed from it should supersede unreliable wind machines, even at much greater expense. The windmill was doomed as milling grew up from a community service to large-scale manufacturing.

It is an interesting fact, however, that many more windmills are in use today than were ever grinding grain even in the heyday of the old-style windmill; but they are of an entirely different type, of small size, with small, many-bladed wheels, and lightly built of steel. The aerodynamics of these wheels are not so good as in old sail wheels, but the increased blade surface compensates for the disadvantage. These modern windmills are used primarily either to pump water into storage tanks or to charge storage batteries—tasks which can be carried on intermittently and without continuous supervision.

Even this summary account indicates the number and variety of problems that had to be solved before the windmill, despite all prior experience with water mills, became a powerful and dependable machine. These problems, dealing as they did with the subjugation of erratic air currents to the doing of useful work, gave a great and continuing impetus to the study of natural phenomena and advanced the mechanical arts enormously.

The builders of water mills and windmills were neither physicists nor mathematicians and formulated no natural laws. But they explored the operation of many of these basic laws of nature and prepared the way for their ultimate definition: they discovered and applied many of the mathematical formulas which govern the translation of energy from one form to another; and they invented or perfected many of the mechanical devices whereby energy is now transmitted and controlled. When later generations of better-trained men began to apply science to the expansion of production, they used in their research the practical tools with which generations of millwrights had provided them. The centuries between the first and the eighteenth, when true scientific research began to assume the leadership of industrial progress, were a time of slow, fumbling, but cumulative advancement, the tempo of the advance rising sharply toward the end. It was then that foundations were laid for the more spectacular achievements of more recent times.



CHAPTER X

Man's New Power Resources

> If we could realize a complete history of a single tool, as a hammer, a saw, a chisel, a hatchet, an auger, or a loom, it would form a more comprehensive history of the world than has ever been or perhaps ever will be written.
>
> —Thomas Ewbank

THIS story of milling has advanced from the ancient, tradition-ruled empires where grain for feeding millions of people was ground laboriously, by hand, on primitive saddlestones, to an analytically minded world which ground most of its grain by water and wind power. In this progress we can see the expansion of the scope of reason, until it came to guide men's everyday acts as well as their speculative thinking. We have arrived at the point where conscious, professional engineering armed with proven scientific data would soon begin to supplant the traditional, body-bound handicrafts in milling and, in time, in all other productive activities.

Machinery cannot be built by the wisdom of the hands alone, and better machinery does not develop out of precedent only. It was easy to go on making saddlestones, making them as they always had been made; they had to fit the muscular strength and reach of the worker, they must

Chapter head oval. Science and practical experience opening up a world of plenty. From the title page of Böckler, *Theatrum machinarum novum* (1662).

be suited to the body and the hands. But by their very nature machines escape from the limitations of the body, in their motions, their forms, and their dimensions. The complex assembly of revolving wheels, shafts, gears, and stones which became a water mill or a windmill had no reference whatever to the human body, and the hands played no part in its operation except as they exerted remote and relatively feeble pushes and pulls to start, stop, or regulate the action.

To build mechanisms of this kind, men had to act rationally, according to rules and principles which were essentially abstract but must be expressed with exactitude. The transition to rational formulas, of course, was slow, with tradition as always resisting the addition of new knowledge. That probably is why the early water mills were geared to about the speed of grinding of hand-operated querns: experience had proved this speed best in the old mechanism, and so it was maintained in the new. But as fresh experience forced its own recognition, and power machinery became more complex and more precise in its operation, new controlling influences became dominant. They were expressed in measurements, calculations, proportions, ratios, governing the millwright's work. These formulas were the body of a new kind of more rational tradition.

It was in this process that mathematics slowly came into use as the most reliable and versatile of practical tools, by men who knew nothing and cared less about the theory of mathematics—a turning point in the history of thought, which ultimately would affect mathematics itself even more drastically than it affected the mechanical arts in which it occurred. Previously mathematics had been regarded as a purely abstract science. Plato had said that the mathematical soul adheres to "abstract numbers, steadily declining the discussion when any numbers are proposed which have bodies that can be seen and touched." But Plato lived twelve hundred years or more before the Arabs introduced Arabic numerals, algebra, arithmetic, and the decimal system to the European world. Anyone who has tried to calculate by means of Roman numerals will appreciate the advantage of the Arabic innovation, with its fundamental contribution of the number *zero*. The Greeks had struggled endlessly to explain how *nothing* can exist. Without worrying about it, the Arabs, following the Hindus, assumed *nothing*, gave it a symbol, and thereby made mathematics not only a convenient tool which even a humble, unlettered millwright could use, but also the precise and flexible instrument which both science and mechanics require. Thus by being put to work in a manual craft, mathematics became of practical service without losing its standing as an abstract science.

The millwrights' growing knowledge, for a long time, did not find its way into books. For the most part these men could not read or write, and their learning was recorded only in oral maxims and rules of thumb. Principles were not generalized, and therefore it was seldom possible to give them any broad application: it was necessary to explore them independently as each new mechanical problem arose. The idea of looking in books for information did not occur to the working mechanic. As late as 1732 Thomas Lombe was granted £14,000 by Parliament for the introduction of silk-throwing machinery into England, although Zonca's 1607 depiction of the very mechanism he introduced is known to have stood on an open shelf in the Bodleian Library at Oxford from at least 1620.

Yet a great body of working knowledge accumulated. A master workman handed on his acquired experience to his apprentices, and spread it abroad when asked to construct a mill in a new region. Early millwrights, like all master builders of the Middle Ages, were great travelers; they went where there was work to be done, and having finished a job in one place they were forced to seek employment somewhere else. Thus they learned by observation, and also taught as they traveled.

While this body of practical knowledge was accumulating, parallel but unrelated work on the theory of energy was being done by other people with a quite different bent, many of whom, unfortunately, had never paid any particular attention to mills or any other mechanical devices. They were hampered in their efforts by the same kind of difficulties as the mill builders. While the latter were putting their faith in undershot wheels, where the impact of the water could clearly be seen, the theorists were struggling with the theory of energy by means of the sixth-century doctrine of impetus, which held that a body exercises force by virtue of its weight in motion. The difficulty with this doctrine was that it did not recognize the energy stored up in a body at rest. Without the clarification of ideas centering on energy of position, severe limits were set on the advancement of both science and the mechanical arts.

What the thinkers were struggling toward, over the centuries, was the concept of inertia with which Galileo was familiar in the early seventeenth century, and which was eventually summarized in the late seventeenth century in Newton's First Law of Motion: "A body at rest remains at rest, and a body in motion continues in uniform motion in a straight line, except as it is acted on by an external force." Every body in the universe is at rest or in motion at such a velocity—including zero velocity—as brings the forces acting upon it into balance. If an unbalanced force continues to act, the velocity in the direction of the force will continuously accelerate.

This concept, and other related physical laws first clearly defined by seventeenth-century thinkers, made possible the conjunction of science and mechanics. By considering forces dynamically—that is, in relation to the time and distance over which they act—men finally began to understand better the operations of nature and the operations of the machines they were building. As an example, it was because of this clarification that the overshot wheel could be proved superior to the undershot. Although it is true that this definite proof was not given until almost two generations after the statement of Newton's law, clearer thinking had enabled a great many people, long before that time, to reach the conclusion that the overshot wheel was to be preferred wherever the amount of fall and other natural conditions permitted its use.

At present it is almost impossible to trace the accumulation of mechanical knowledge in any detail prior to the sixteenth century, or to demonstrate the continuing effect it must have had on the development of scientific theory. A painstaking search of old documents might piece out this story. With respect to water mills and windmills alone, hundreds of depictions are to be found in old manuscripts, often as casual features of landscapes, real or imaginary. These depictions have never been thoroughly studied. Nor have the countless references to mills in old writers been collected, compared, analyzed, studied with care; they have been noticed, if at all, chiefly for earliness or quaintness. To piece together their implications would be difficult, but rewarding. As Sarton points out with reference to the related problem of the growth of scientific ideas, "Nowhere is the growing maturity of the West at the beginning of the Thirteenth Century more certain than in the field of pure mechanics. I say more certain, not more obvious—for this is not obvious at all, and not one mediaevalist out of a thousand would be able to recognize it by himself. In the course of the century we witness a true mechanical rebirth."

This was the century in which the windmill was rapidly spreading, and it happens that Sarton cites a theoretical innovation of direct pertinence to its principle of operation. Jordanus Nemorarius, who died in 1237, in discussing gravity introduced the notion of *gravitas secundum situm*, or component of gravity along the trajectory. However it be with this idea so far as gravity is concerned, this is exactly the force which, acting on windmill sails at a right angle to the direction of the wind, causes them to rotate. What Jordanus was struggling with, in fact, was the idea of the parallelogram of forces, which was later fully clarified by Stevinus, who died in 1620.

The seventeenth century's achievements in the clarification of physical theory were preceded by an intense preoccupation with practical mechanics throughout the sixteenth century. There was an outburst of inventive activity, and a growing tendency to record mechanical facts on the printed page. A spate of books testifies to this keen interest in mechanics, and from here on the record of milling progress gains continuity.

In 1502 Boller is credited with the first power-agitated sieve; Cardan's *De subtilitate* of 1550 has a diagram of a hand-operated sieving apparatus permitting four separations (both reproduced in Figure 54). In 1537, according to Olaus Magnus, treadmills were in use for milling in northern

Europe. Though one had been described by Vitruvius, we have no record of its use in the classical or medieval periods. Leonardo in the early sixteenth century showed a man treading on the outside of a wheel to rotate it, while Agricola (1546) had men working a wheel from inside it, as well as another machine in which they rotated a horizontal platform. Finally, in 1573, John Payne slanted the platform so that the weight of the men would be added to their muscular force to move it. Here we have a steadily increasing rationalization of a single apparatus. In Cardan's *De varietate rerum* (1557) there is an analysis of the action of the sail wheel of a windmill which we have already had occasion to quote as showing that he, like Francis Bacon a little later, was familiar with the function of the leading edge of the sail (page 127). And of course this was the century in which the windmill itself underwent a very rapid improvement, culminating in the appearance of the cap mill.

In 1569 Jacques Besson's *Theatrum instrumentorum et machinarum* was published in Paris, and soon thereafter, also in Latin, at Leyden. Various other editions later appeared in German and French. An amazing book of sixty folio drawings with their explanations, it contains only instruments and machines that had been invented or enriched by Besson. In the words of his editor—he died before the book was published—"one can say without boasting that this book is in no wise the work of a bird man, a delicate person, or one nourished on shadows; but of a person who suffered many blows and accomplished great things." In other words, Besson was a practical mechanic and not a mere theorist. Among his many machines and instruments, of special interest to us is his turbine-like tub mill with spiral blades (Figure 57), which he modestly compares with wheels in use at Toulouse, although his editors assure us that the Toulouse blades did not curve around the wheel.

But by far the most important record of sixteenth-century mechanical ideas and practices is Agostino Ramelli's magnificent *Le diverse et artificiose machine*, which appeared in 1588. Its 195 finely engraved plates, with descriptive text in French and Italian, give a marvelous conspectus not merely of the machinery of the time, but of the way the best contemporary minds were thinking about machine operations. Only Agricola's *De re metallica*, published in 1546, compares with it, and Agricola's work deals only with mining practices, a topic not covered by Ramelli. The highly logical, almost formalistic character of sixteenth-century thinking in the mechanical arts is strikingly brought out in Ramelli's plates. His machines are powered by hand cranks, treadmills, weights, springs, three types of water wheels, and wind, and he delights in showing different ingenious arrangements of gear trains and other transmission systems whereby power can be made to activate his pumps, millstones, hoists, jacks, etc.

Ramelli, with a South European viewpoint, includes but three windmills in his book, although two of these give handsome skeleton views of the post mill and cap mill and convey an excellent understanding of windmill construction. He illustrates eight water-powered flour mills; four show undershot wheels, two are overshot, and three are of direct-drive construction — one illustration combines an overshot and a direct-drive wheel. The undershot mill reproduced in Figure 52, like all his examples, is fitted with a damsel arrangement to agitate the shoe of the hopper. He includes an ingenious floating mill, and in one instance shows a tentering device, in another a bolter shaken by mill power. Other mills are powered by animals, by men using cranks or working treadmills, or by weight mechanisms.

But Ramelli's most important milling illustration is his famous roller mill (Figure 66), which some have thought was the mill invented by Charles V of the Holy Roman Empire with the help of his mechanic-watchmaker Turriano, after Charles' abdication and retirement to the Monastery of St. Just in 1556. We are told that this mill was small enough to be placed in the sleeve of a monk's gown and that it was marvelously productive; but no further description of it has come down to us. Ramelli's illustration shows a rotating roller with spiral groovings — two most pregnant ideas which lay dormant until the nineteenth century, when the

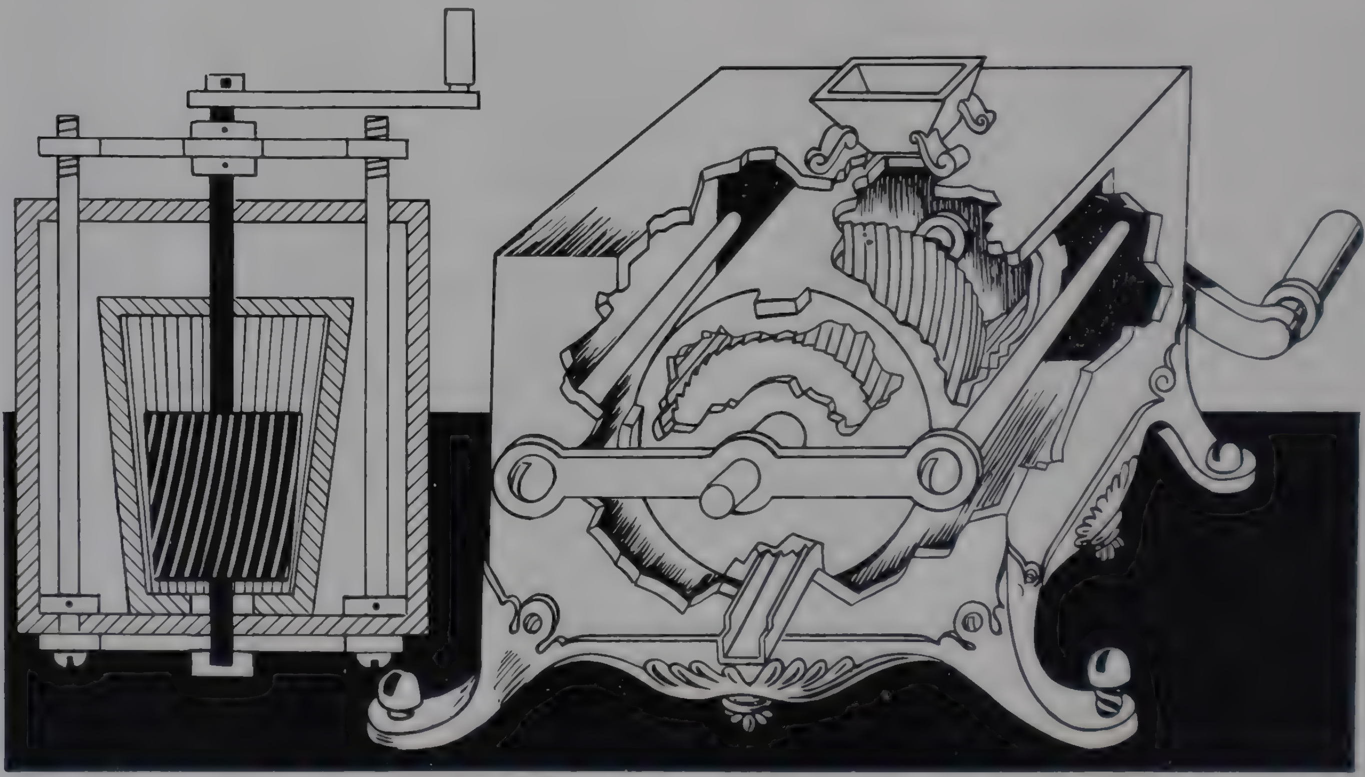


Figure 66. Ramelli's roller mill (1588), shown in cutaway view at the right and in cross section at the left. The inside corrugated cone section can be moved back and forth for adjustment by means of the long side bolts. Since the side of the roller has a slightly steeper pitch than its containing shell, the mill can be set to grind over only the last small portion of the space between the two. Grain from the outside hopper falls into the open space at the back of the shell, and is drawn into the grinding area by the corrugations as the cone is rotated.

invention of the double roller mill with spiral groovings revolutionized the art of milling. So far as we know these ideas were utterly without precedent in Ramelli's own time. An effort has been made to compare this mill with the lower half of an hourglass mill set on its side, but the comparison is forced. It was the combination of the roller core with its suspension inside the casing, plus the spiral corrugations, plus the hopper space inside the casing, that enabled Ramelli's mill to work; and it was the arrangement for bringing the two surfaces close together over only a short distance at the far end of the two cones that enabled it to work well. The person who designed this mill possessed an astonishing inventive genius, but his work had one fault – it was too far ahead of the practices of his time to have any immediate practical value.

Another hand-operated roller mill – that of Böckler dating from 1662 – resembles the modern roller system even more closely than does Ramelli's mill (Figure 54). Because Böckler's roller is eccentric to the concave block near which it rotates, grinding takes place along a straight line, rather than all over a surface as with millstones, or all around a circle as with Ramelli's mill. Böckler's method is the one used in modern milling, a second rotating roller taking the place of his concave block. The meal from Böckler's mill was served into a bolter agitated by the same crank that rotated the roller.

The body of mechanical tradition brought to a brilliant focus by Ramelli and carried on by Böckler and others incalculably influenced the growth of science. "Trial and error, verification by putting a theory into practice, which had always been the everyday procedure of craftsmen, became the everyday procedure of scientists." Machine design in the sixteenth century encouraged bold thinking, but it was a controlled boldness, whereby wide-ranging ideas were brought to the test of action.

Mechanics and science were drawing together, toward a union that would be of immense benefit to both. Leaders of seventeenth-century thought such as Francis Bacon and Robert Boyle recognized its necessity, but its culmination was delayed by the fact that science for centuries required better craftsmanship than industry could provide – as, of course, did industry itself. The precision essential to modern mechanics was for long unattainable. In the early seventeenth century, for example, Galileo had to make his own telescopes, and was impeded in his studies of gravitation by the imperfect timepieces and poorly shaped spheres he was forced to use. In the late eighteenth century, Watt was greatly hindered in improving his steam engine by the difficulty of getting sufficiently true cylinders for his pistons, though he wanted them accurate only to "the thickness of a worn shilling."

Nor was the marriage of the empirical and rational faculties (Francis Bacon's phrase) easily consummated – both parties were often self-centered, opinionated, and skittish. Gray, the English millwright, expressed his scorn of theory, when he wrote in 1816: "Machines or engines seldom owe their origin or improvement to considerations deduced from the laws of motion. . . . It is from long experience, and repeated trials, errors, deliberations, corrections, etc., continued throughout the lives of individuals, and by successive generations of them, that the practical sciences derive their gradual advancement from awkward beginnings to their most perfect state of excellence."

On the other hand, Oliver Evans, in the preface to *The Young Millwright*, published in 1795, laments the fact that those versed in science so often lack practical knowledge, and vice versa. He instances Smeaton as the only person who to his knowledge possessed both. He might well have added himself, though he was self-taught. Many of the great eighteenth-century inventors — Hargreaves, Arkwright, Crompton, Cartwright — were untrained in mechanics and at the same time were far from being scientists. But their work would have been impossible without the blind-alley efforts of numberless mechanics on the one side, and without the often visionary theories of numberless thinkers on the other. It was their right instinct that brought the two together, and began the practical working alliance of science and mechanics celebrated on the title page of Böckler's work (Oval, Chapter X). This alliance has resulted in the marvels of modern production and accelerated the advance of modern scientific thought; at the same time it has created many of the grave problems that face the world today by making enormous powers available to men who are not always of good will.

Out of the growing mechanical-mindedness induced originally by the grain mill and exercised in the development of many other kinds of machinery, new trades — in time to become professions — began to take shape. In the field of milling the millwright emerged more clearly as a highly expert specialist. We have definite proof of his attainments in the Dutch mill-books of the eighteenth century, led in 1702 by Jousse's *L'Art de charpenterie*, with its precise instructions for the building of a windmill. A number of enormous and impressive folios, devoted exclusively to this subject, followed: Limperch's *Architectura mechanica* (1727), van Natrus' *Groot volkomen moolenboek* (1734), Leupold's *Theatrum machinarum molarium* (1735) — more nearly a scientific treatise; van Zyl's *Theatrum machinarum universale* of 1761 (Figure 63). In these books we find a wealth of carefully detailed, accurate, and complete drawings — plans, elevations, and sections — quite adequate for construction purposes.

These works had a solid background of milling experience behind them: milling, weaving, and foreign trade had grown to large proportions in Holland. In fact, a basic change in the economy of the Western world was under way and gathering momentum. The activities of men were becoming less self-sufficient and more specialized, as larger and larger requirements were laid on every productive operation. More and more, also, a whole apparatus of business became necessary to enable the expanding society to transact its complex exchanges. The responsibilities of management, covering the initiation of new enterprises as well as their control, were taken over by a new class of specialists under a progressive division of labor. In the early modern period the state had controlled the expansion of industry and commerce—witness the various chartered companies. But as time passed, the pressure of new activities burst the bounds of state regulation and overflowed into the more fertile fields of free enterprise.

The change was helped by the spread of the business spirit. In the medieval period, the productive activities of life were not an accepted avenue to riches for peasant, artisan, or aristocrat: to become wealthy a man hoped to find a treasure, inherit a feudal fortune, become a favorite of royalty, go soldiering, become a pirate or a successful alchemist. Now, however, more commonplace roads not only to wealth but power were opening to able men of all ranks. By the end of the seventeenth century the new business of starting new businesses was so popular that Daniel Defoe in his *Essay on Projects* (1697) called his time in still backward England "the Projecting Age." Yet it was a long time before business became as respectable as less productive means of gaining wealth or a living. Though Adam Smith's *Wealth of Nations*—"a Declaration of Independence for Industry"—was published in 1776, even in nineteenth-century England manufacturing was still regarded as an undignified occupation, as the novels of that time clearly show.

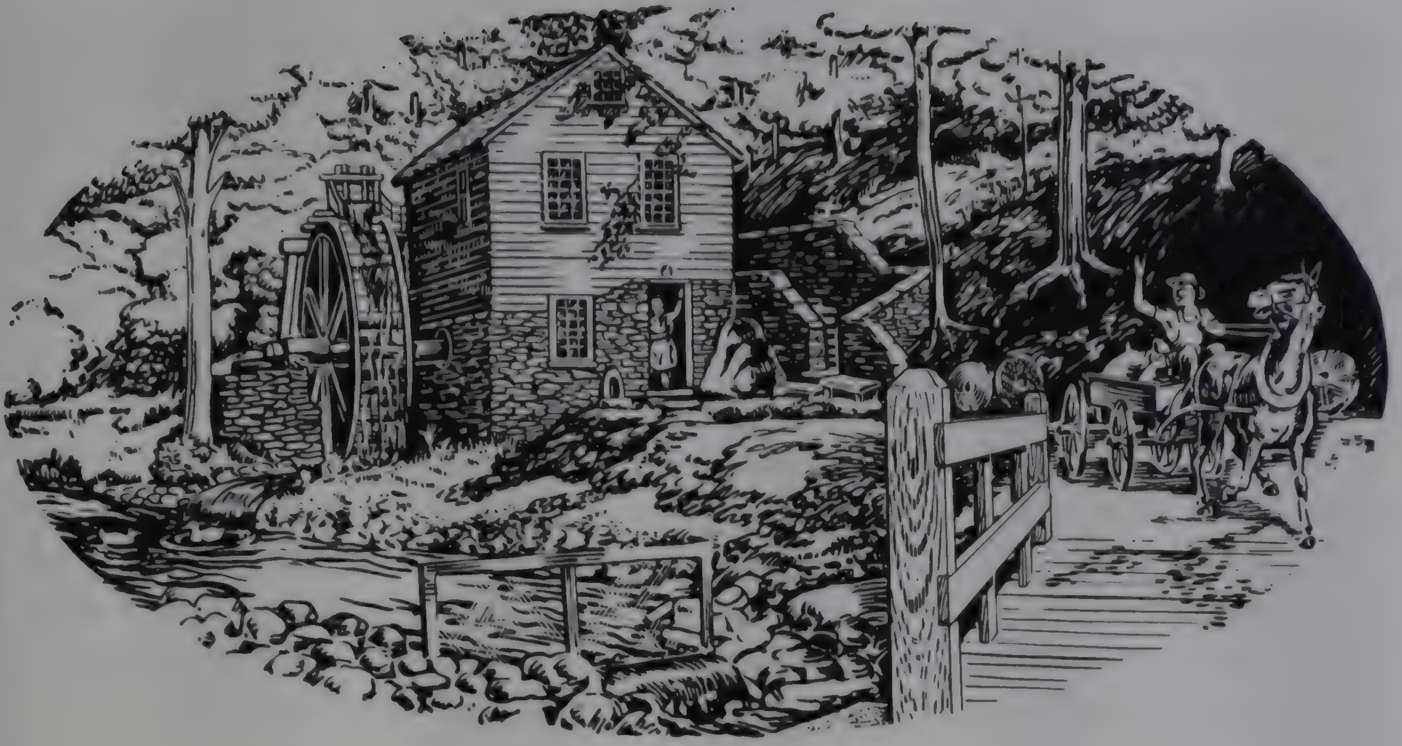
The water mill and windmill played a decisive role in the new scheme of things. As they became larger and more elaborate, their greater output demanded widespread markets. The full potentialities of power production could be realized only as the social needs of the populace expanded, guaranteeing consumption of the greater volume of goods that flowed from the mills. This again demanded better roads and busier waterways, so that the goods might be distributed more widely to a broader market.

The growth and expansion of milling had produced the artisan millwright, and then, merely by continuing, it eliminated him. Large mills could not be built by simple experience and rule of thumb; too much money was involved, the detail was too complex, there were too many new and untried factors. By the beginning of the eighteenth century really large mills were being constructed, of which the largest was Lombe's silk-spinning factory at Derwent, England—a five-story building 110 feet long, lighted by 468 windows, in which a single water wheel 23 feet in diameter turned 14,000 other wheels. As water powers of larger head were brought into use, posing delicate questions of millponds, dams, sluiceways, operations under maximum and minimum heads and choices between water wheel types, a new need for sound theory was felt in mill construction. The millwrights had not been entirely ignorant of science—their books often began with definitions of body, force, motion, *vis inertiae*, gravity, friction, momentum, and the like, and dealt with such subjects as the mechanical powers, the strength of materials, and the relation between force, friction, and work accomplished—but their acquaintance with the body of scientific knowledge and theory was definitely at second hand, and so vague as not to be helpful in a novel situation.

It was in response to the demands of mill design and construction that the modern profession of engineering was born. John Smeaton, who contributed so much in this field, coined the name of "civil engineer" for himself in 1761. This was to distinguish himself from the "military engineers" such as Vauban who had pretty well monopolized the title up to that time. From Smeaton's day and on into the nineteenth century, engineering was largely concerned with perfecting the water mill, by that time used for a multitude of manufacturing purposes. During this period the windmill slowly became a less significant factor in the growth of industry, as the Low Countries fell behind England in industrial progress, perhaps in large measure because they had to depend on an uncertain and after all clumsy source of power.

But the same forces which acted to eliminate the millwright in favor of the engineer, and the windmill in favor of more informed uses of the water mill, also finally pushed the water mill into the background as the prime mover of industry. With the invention and improvement of the steam engine in the late eighteenth century, and the growth of improved means of transportation in the early nineteenth century so that cheap, dependable, flexible power could be obtained anywhere, the water mill found itself marooned in disadvantageous locations away from ports, centers of trade, raw materials and markets, and condemned because of its sometimes unreliable and, in most instances, inadequate provision of power. Thus the water mill played only an initiating role in the most recent and climactic phase of the Industrial Revolution, which started in the eighteenth century and has now been almost consummated.

In this change a most important alteration of our life patterns is symbolized. With the steam engine the machine age of the last two thousand years began to yield to the energy age, into which our world is moving at constantly accelerating speed—with that acceleration, in fact, which must result whenever a force is continuously applied. But before we make an effort to understand the new age of energy in terms of the changes it has wrought in milling, we must first turn to America and trace the development of milling in the region which was eventually to become the United States. In the new field of America, especially from the late eighteenth century on, we shall find many aspects of the expanding life of today making their first tentative appearance; and we shall find also a quick willingness to adopt methods arrived at elsewhere.



CHAPTER XI

Milling Comes to America

> God hath sifted a nation, that he might send choice grain into this wilderness.
>
> —William Stoughton

THE lapse of a century and a quarter between Columbus' voyages and the establishment of permanent colonies in what is now the United States was not due to the poverty of the region — it was rich even in immediately usable resources; but to live successfully here, Europeans had to develop new ways of life, forged by necessity out of the resolution of their own hearts and the possibilities of the new country — a challenge they were slow to meet.

The first white men to settle in what is now the central and north-central United States found the country back of the coast densely wooded and sparsely inhabited by Indians who were living in fairly stable groups and working the soil by a nomadic agriculture very similar to that of Europe, away from the Mediterranean, about 2000 B.C. Without Indian clearings to lighten their labors, and counsel and active help from the Indians, the first settlers would have found it even harder to survive, unequipped as they were with either civilized tools or primitive techniques.

Chapter head oval. Old American water mill at Norris, Tennessee, almost in the shadow of the Norris Dam.

The coast Indians were much less addicted to hunting and fighting than we commonly think; they were usually friendly until incited to enmity by the invaders. It was some time before the English in particular came in contact with more mobile or belligerent groups, or with the remarkable confederation of tribes occupying what is now western New York, who seem to have been on the verge of passing from barbarism to civilization at that time.

The Indians of eastern North America cultivated an abundance of edible plants, especially Indian corn, or maize, along with squash, pumpkins, and beans. These plants were totally new to Europeans, and the colonists had to learn to raise and use them before white settlements could so much as survive in the New World. Corn in particular was a new master grain, comparable in importance in the life of the Indian to the European's wheat, barley, and rye, and destined to become with wheat one of the two principal food crops of modern Western civilization.

The evidence hints that the Indians of northeastern America themselves had not been in possession of corn for many generations before the coming of the white man, although its introduction from the Southwest was sufficiently ancient to have made the grain a part of the legendary equipment of the tribes. While Verrazano about 1510 noticed no signs of agriculture on Cape Cod, in 1601 Gosnold found plenty. The Indians planted their corn seed by seed, three or four to a hill, which in New England was fertilized by a herring or two; they then kept the ground around their plants free from weeds—a quite new procedure to Europeans, who were accustomed to sowing field crops broadcast and letting them fight it out with other growths. Copying the Indians, the early settlers were practicing intertillage between the rows for about a hundred years before Jethro Tull recommended it in his *Horse-Hoe Cultivation*, published in England in 1738.

The European eventually changed the Indian method in one respect. With no domestic animals whatever except the dog, the Indian weeded and hilled by hand with wood and stone tools and cultivated only immediately around his plants, leaving most of the planted area untouched. This practice would be altered when Europeans began to import animals for use in farming. But first the scarcity of good forage crops had to be overcome. From Virginia north along the coast the two chief pasture plants when the white man arrived were rye grass and broom straw, the latter "so rank, hard, and dry, that they make their brooms of it." The clovers, timothy, alfalfa, bluegrass, the lawn grasses, were lacking. Only our prairies had a suitable forage cover for animals before the advent of the white man, and the prairies were almost a thousand miles and two hundred years away from the first coastal colonists. Thus, in addition to the extreme difficulties of transporting cattle to the New World, better forage plants had to be imported and domesticated before herds could multiply and grain crops expand.

The first cattle arrived at Plymouth in 1624, four years after the settlement, but these were probably cows rather than oxen, since the colonists there had no plow until 1632; there were but 37 plows in all the Massachusetts Bay settlements in 1637. These were, of course, the heavy European implement with wooden or roughly shod moldboard, requiring oxen and at least two strong men to handle them. A good plow was not devised until the eighteenth century. The arrival of oxen made a great difference: Edward Johnson in 1637 noted: "It was with sore labour that on [one] man could Plant and tend foure Acres of Indians Graine and now with two Oxen hee can Plant and tend 30." The soil in some places was so hard that the first breaking required ten oxen. But by 1642 the region had 12,000 cattle and 3,000 sheep, a striking sign of the progress made in less than a generation. Grain crops were increasing to the point where serious attention had to be given to milling.

The Indians of what is now the eastern United States everywhere had two techniques for grinding corn meal: toward the south the metate-mano combination was in general use (Figure 67), while farther north the mortar and pestle were more usually employed, with the mortar often in the form of a large hollowed-out tree trunk (Figure 20). The grain was usually dampened before pounding. Mortars of hollowed stones were also used, with the grinder large in proportion to the lower stone, so that it could be rocked or turned with a two-handed grinding motion rather than a direct pounding action. The grinding of Indian corn was never so critical an

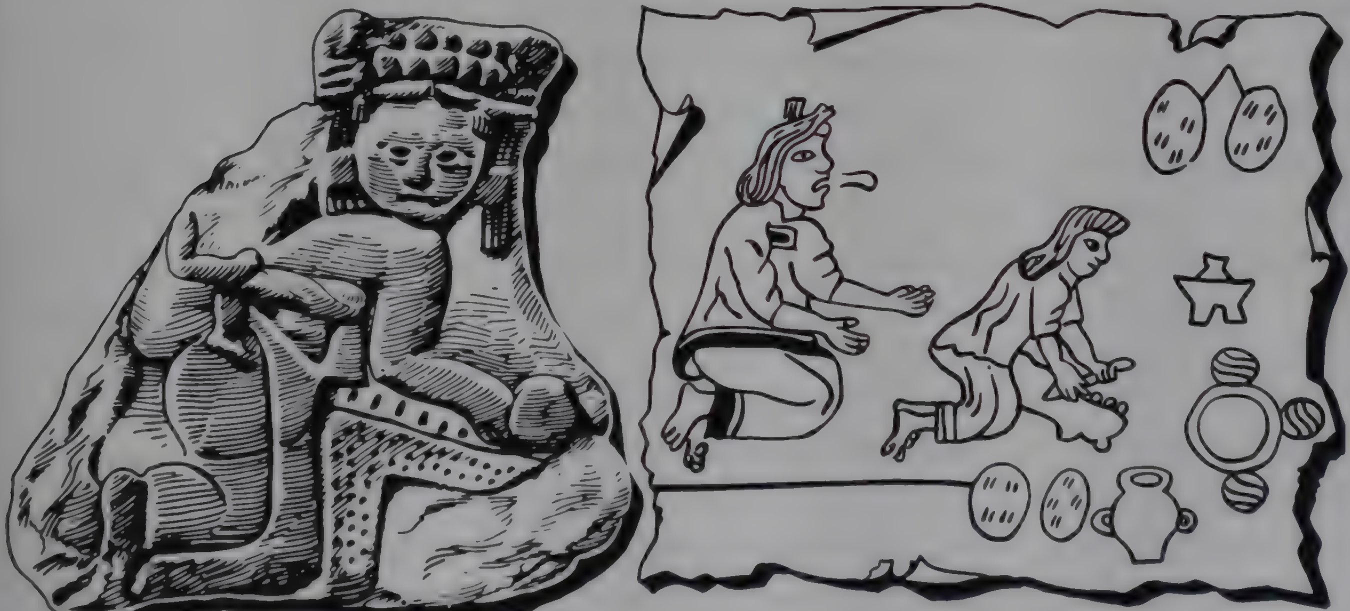


Figure 67. At the right, a Mexican mother teaching her daughter, aged thirteen, to use the metate. From the Mendoza Codex, a book of instructions for the young, reproduced in Kingsborough, *Antiquities of Mexico*. At the left, an old Mexican ocarina with an incised depiction of a woman grinding corn.

operation as the grinding of wheat. Except for a very thin outer sheath, which the Indians had learned to remove with the aid of a mixture of lye-ash and water, the corn grain is entirely edible: our whole-grain hominy of today is an often delectable descendant of the Indian corn so treated. Whole-grain corn parched in the fire (under primitive conditions protected by the natural sheath or "husk" of the ear) is also nourishing and palatable, and was a staple in the diet of many early settlers.

From the Indians the white man learned many ways of preparing corn, from roasting ears and hominy to puddings, from corn pone to johnnycake — a corruption of *journey cake*, so called because of its keeping qualities. Without the knowledge of these and other Indian foods, the colonists would have been hard put to it to maintain themselves in early days.

At the same time Old-World plants were very early imported into the New World. Wheat was brought to Mexico by the Spaniards in 1529, and it had been planted on Roanoke Island, off the coast of North Carolina, by the temporary settlement of 1585, as well as by Bartholomew Gosnold on a visit to one of the Elizabeth Islands, between the mainland and Martha's Vineyard, in 1602. In 1607 at Jamestown, during the first growing season, both corn and wheat were planted, although neither grew satisfactorily then or for a number of years.

The experience of the Virginians was typical of the other early settlers (except the Dutch). Usually seeking easy roads to wealth, poorly equipped, and unfamiliar with primitive conditions, years passed before they were able to provide themselves with a minimum of necessities. The first grist windmill was not erected at Jamestown until 1621, fourteen years after settlement; before then the colonists probably had neither enough crops to justify power milling nor the means of providing machinery for grinding. At first sawmills were more urgently needed than grist mills, for sawing wood by hand was very hard work and called for man power, whereas grain could be ground by women at home. Also, before the building of serviceable roads, the problem of transporting grain even a few miles to a central mill was a serious one. So when we learn that Virginia in 1649 had four windmills, five water mills, and "many horse-mills," we can be sure that the colony was well on its feet.

These early mills were invariably community mills, operated on a toll system: that is, they served an area of not more than eight or ten miles' radius at the most, and often smaller, the limit of a day's travel for farmers at the time; and the miller took his pay or toll in a portion of the grain brought to him for grinding. The miller could grind his toll receipts for his own use and for sale to town dwellers or others who did not raise their own grain. This system, imported from Europe, persisted in many sections of the country until the twentieth century, and yielded nowhere except to the establishment of long-distance transportation systems, first by water, then by turnpike and water, finally by turnpike, water, and railroads.

But the Virginians, and in fact each group of colonists in turn, had to develop a money crop or other source of revenue, as well as provide for their daily necessities, if they were to prosper. In the seventeenth century this could not be grain for the English markets, for at that time England was her own granary. The colonists therefore had two recourses—the discovery of new markets for grain, in the case of colonies where it grew easily, and the development of other marketable products. By 1631 corn was being exported from Virginia to Salem, and by 1633 the trade was at least 10,000 bushels. But tobacco soon proved to be an easier money-maker, and became the first ready provider of the cash needed to buy Old-World manufactures. From about 1617 on the great tobacco plantations flourished. The colonists did not suspect that repeated planting of tobacco on the same fields would result in soil depletion, nor realize the care tobacco would demand for continuous cultivation, much less the speedy price decline as its novelty vanished and the market was flooded.

In Massachusetts the Pilgrims were so unfortunate as to land in the depth of winter in a region whose cyclonic extremes and changes even today make weather prediction more a prophetic art than a sober science. It was a country where wheat grew less well than corn, and where even corn did not always yield a good crop. The colonists were greatly helped by the famous Indian Squanto, but he died in 1622. By 1624 they had accumulated at least a small surplus. Writing in that year and no doubt using "corne" in the generic sense to cover any grain, Governor Bradford said: "They begane now highly to prise corne as more pretious than silver, and those that had some to spare begane to trade one with another for smale things . . . for money they had none, and if they had, corne was preferred before it." This beginning of success must have been small, however; for though we hear of millstones being imported into Massachusetts in 1628, the first powered grist mill—again a windmill—was not erected until 1631, in Watertown. Probably in the same year a sawmill was erected on the Piscataqua, at what is now Portsmouth, New Hampshire.

As in the case of Virginia the appearance of grist mills can be taken to mark a turning point; by 1642, 15,000 acres were in tillage and 1,000 acres in orchards and gardens. The first mills were probably wind-driven and of post-mill type, as becomes certain in the case of some when we learn of their being removed from one location to another. They were preferred to water mills because they were easier to construct, dams, races, and water gates being more difficult to build than structures of timber alone.

But water power was bound to be preferred over wind power in the colonies after the first difficulties had been surmounted, except in a few flat areas such as Cape Cod or Long Island, where wind conditions are especially favorable, or in the Dutch settlements generally, where windmills were a home tradition. The eastern coast of North America is characterized by an abundance of streams and coastal indentations, with low falls and rapids not far from the sea. And so we hear of a water mill at Dorchester in 1633; of others in Virginia by 1649; and it seems probable that water power ultimately won out even on Dutch Manhattan, which was hilly and in early days well supplied with small streams. Large water powers were seldom utilized anywhere until much later, and then primarily for manufacturing. The preferred location was off a small stream, often a mere branch, on a millrace beyond a small dammed pond (Oval, Chapter XI). The building of even so modest a combination was a major undertaking under primitive conditions.

Considering all the difficulties that faced them, the colonists moved very quickly from the mortar and similar primitive methods of domestic grinding to power milling by wind or water. At first they did not make much use of the quern; this implement is almost never mentioned in the inventories of estates that have come down to us. Later on, the quern had its day in isolated backwoods areas, where not even community milling was feasible because of the distance between settlements and the lack of good roads, while merchant milling of purchased grain for shipment was wholly out of the question. This use of the quern persisted even into the twentieth century (Figure 49).

The rapid change to power milling was helped in Virginia by the necessity of buying food supplies for tobacco-plantation workers, and in New England by the growth of deep-sea fishing, which with lumbering, leading finally to shipbuilding, occupied the New Englanders' time and supplied them with cash. The Pilgrims had come to America with the expectation of devoting a large part of their effort to fishing, but for a good many years more urgent matters claimed their attention. By 1665, however, 1,300 vessels were regularly engaged in deep-sea fishing. These fishermen, and later the whalers, the shipbuilders, and the manufacturers, had to have bread. As the early imports of grain from Virginia, Maryland, Connecticut, and New York show, Massachusetts was regularly faced by a deficit of grain even after the early days of hardship had been left behind.

Wheat never really flourished in New England – it had "almost passed out of cultivation with the third generation of farmers." Grain farmers more and more turned to corn and to rye, the most dependable of the European grains then as now under the severe New England conditions. Corn and rye mixed made "rye and Injun" – the *maslin* of old New England and the equivalent of what we now call Boston brown bread. In an effort to revive wheat-growing, Massachusetts taxed imports to provide a bounty for farmers, but "the duty could not counteract climate and soil nor feed the fisherman." A century later, in 1796, George Washington referred to New England as a meat- and fish-producing region.

For a brief period in the seventeenth century the Connecticut Valley did manage to produce a surplus of wheat. The grain had been grown successfully in 1641 at Hartford, but production was so well encouraged by the paternalistic government that by 1644 there was a glut and the price fell drastically. Resort was had to export; data are scarce, but we know that in 1652 a single grower – John Pynchon of Springfield – shipped 1,500 bushels of wheat, or almost 100,000 pounds. But Connecticut wheat soon went the way of Massachusetts grain – "blastings, mildews, caterpillars, worms, tares, floods and droughts" took their toll, and production declined. In 1726 the government rightly tried to eradicate the barberry bush, which we now know is an intermediate host of the wheat rust fungus, but nothing could be done to prevent the transfer of extensive wheat-growing to more favorable regions. In 1757 Dr. Jared Eliot noted of eastern Connecticut that "many are inclined to remove to new places that they may raise wheat," and by 1800 the region was importing most of its grain and flour.

New York City, then New Amsterdam, emerged as the first really large American flour-milling and marketing center in the second half of the seventeenth century. It had been founded as a fur-trading post in 1619. The Dutch with characteristic thoroughness began in 1623 to settle carefully chosen, well-equipped families in the territory they hoped to control – not only in Manhattan but on the North River at Albany, over the East River on Long Island, across Jersey on the South or Delaware River, and on the Fresh River at Hartford – all centering on New Amsterdam with its magnificent harbor. The ease of transport by water from all these settlements was a decisive influence on their prosperity.

The up-Hudson country around Esopus in Ulster County, near Kingston, and to a lesser extent Long Island and the nearby Jersey flatlands, became wheat-growing territories for what was soon an extensive export trade. An old view of about 1631 shows a single windmill on Manhattan; there must soon have been others, as well as water mills – as early as 1661 a water mill stood by Freshwater Pond, near present-day Wall Street. By 1645 flour and hard breads were being exported, in part to New England, but mainly to the West Indies, where molasses was picked up for manufacture into rum. The rum was used mainly to exchange in Africa for slaves, but also for local consumption and to obtain furs from the Indians.

After the English annexation of the Dutch holdings in 1664, the trade became even more extensive, so that New York City became the world's largest merchant-milling center and, in fact, the world's first major wheat market. In 1678, when wheat exports stood at about 60,000 bushels a year, the miller-merchants obtained an act prohibiting the manufacture or bolting of flour anywhere in the province except in New York City. The

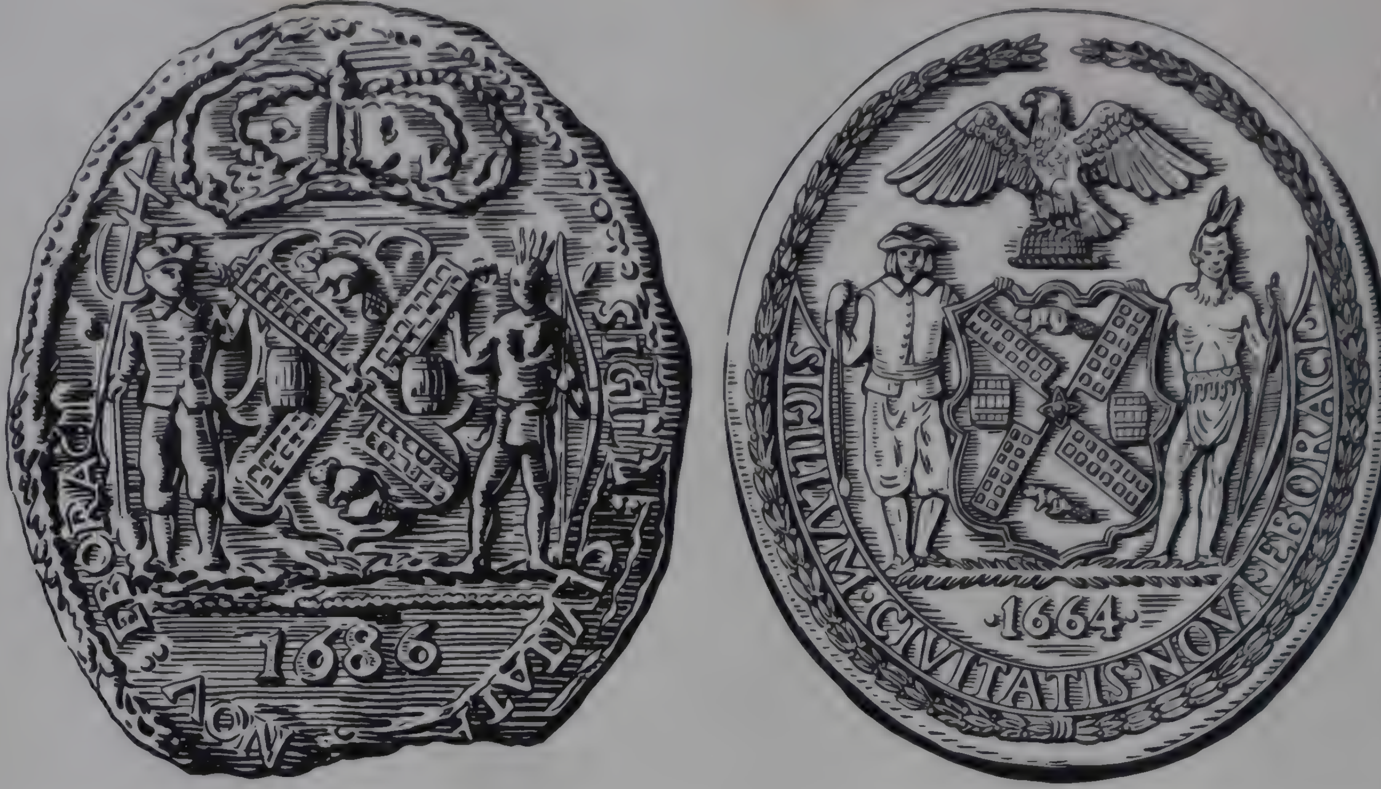


Figure 68. Seal of New York City, in one of its early designs (left) and in its present form (right). The central shield is quartered by windmill sails, and has beavers and flour barrels in its divisions to symbolize the trade in furs and breadstuffs. A sailor with sounding line, and an Indian stand beside the shield.

packaging of hard breads for the West Indian trade was also regulated because of many frauds.

The manufacture of flour had become so important by 1686 that the city's coat of arms (Figure 68) was redesigned to include windmill sails and flour barrels, in addition to the beavers already present to symbolize the fur trade, which itself was largely supported by the rum obtained in exchange for breadstuffs. There was great dissatisfaction with the monopoly law – it initiated perhaps the first of many conflicts in New York between upstate and metropolitan interests – and when it was finally repealed in 1694, the city's commerce was greatly disturbed for a time.

It is apparent, however, that the city's grain trade did not suffer a fatal blow. Statistics that have come down to us for the three years following the end of the French and Indian War in 1763 show total annual exports of somewhat over £500,000, with agricultural products amounting to about four times the total value of timber, metals, and manufactured articles; and over three fourths of all agricultural exports were in the form of wheat, flour, or biscuit. The amount of Indian corn exported was insignificant.

Wheat-growing, flour-milling, and trade in breadstuffs continued to be important in the New York City area during the Revolution and the period of the Napoleonic wars that followed, when exports in quantity even flowed to England. But from about 1750 on, New York was actually eclipsed as America's and indeed the world's chief wheat center by the country around Chesapeake Bay and the Delaware River. Here Philadelphia was the chief outlet, with Baltimore and Wilmington and Richmond in time also producing, processing, and exporting large quantities of wheat and its products. Here again, water transport available to wide stretches of productive farm lands was a decisive factor. Until the present century, the center of milling activity has always shifted with the center of wheat production, and so it did in this instance. Even in colonial days the middle colonies, which included New York but not Virginia, were known as the bread colonies.

Tobacco was often grown near the coast, but as the settlers pushed farther inland they turned more and more to wheat, for which the more upland territories were better adapted. Farming was well established at a number of points in Pennsylvania before 1650, although William Penn's settlement dates from 1681. There grew up around Philadelphia a constantly deepening agricultural hinterland, based on some of the richest limestone soils the continent had to offer, well adapted to wheat, and settled by an admirably industrious farming population composed of Quakers and other excellent English stocks and hard-working German contingents. From about 1720, as it became necessary to open up the more hilly and even mountainous backlands, there came large numbers of Scotch-Irish, whose more adventurous frontier spirit enabled them to do well as pioneers. As early as 1726 the back country of Pennsylvania had 100,000 squatters, all holders of small tracts. These pioneers became so adept in driving herds of cattle from their distant settlements to Philadelphia, Baltimore, or (later) Richmond that the animals arrived at market in better condition than when they left home.

But the prime cash crop of the people who lived back from the coast, once they became established, was not livestock but wheat—wheat in a constantly increasing stream. A writer in 1755 stated that Pennsylvania was able to feed its own population, then about 220,000, and "a hundred thousand men besides"—the colony had a surplus production of approximately 50 per cent. The following figures will suggest the mounting stream, although they cover only a single city, Philadelphia, and include only exports, leaving out domestic consumption in town and country:

Year	*Wheat (bushels)*	*Flour (barrels)*	*Bread (casks)*
1729	74,809	35,438	9,730
1752	......	125,960	......
1765	365,522	148,887	34,736
1774	182,391	265,967	48,183
1789	......	369,668	......

The empty spaces in this table indicate a lack of statistics, not exports. The huge quantities of flour and bread exported testify to the prosperity of the milling industry in this area.

In the period just before and just after the Revolution, Philadelphia was the leading American city, well ahead of Boston and far beyond New York, and the solid basis of its prosperity was the trade in breadstuffs. We are fortunate in having statistics of exports from Pennsylvania for the years immediately following the termination of the French and Indian War in 1763, derived from the same source as those already given for New York City. Pennsylvania's exports, almost 100 per cent chargeable to Philadelphia, totaled more than £700,000, two-fifths greater than those of New York; and of this amount agricultural products accounted for about 85 per cent, more than two thirds being breadstuffs. Pennsylvania's exports of wheat, flour, and biscuits were about 40 per cent greater than New York's.

In addition to the great expansion of merchant milling at Philadelphia, as the eighteenth century wore on, Wilmington and Baltimore also prospered. Bishop states that overshot mills on long millraces were introduced on the Delaware in 1762, marking "the commencement of the extensive milling operations for which that place has been so celebrated." In the late 1780's there were 130 improved mill seats within forty miles of Wilmington, although not all of these were devoted to wheat milling – one mill in 1796 ground and bolted flour, ground chocolate, snuff, hair powder and mustard, pressed and cut tobacco, all by water power. The Shallus map of 1799, reproduced in part in Figure 69, shows a few of the more important mills located around Wilmington, for the most part along the Brandywine and branches of the Christiana. It was here that Oliver Evans, America's first and greatest genius in milling, was born and here that he devised his automatic mill.

In 1761 members of the Ellicott family arrived in the Baltimore region from Bucks County, Pennsylvania, eventually set up two mills along the Patapsco, and by their progressive attitude very rapidly became powerful factors in the district. By 1800 Baltimore flour inspections were averaging over 375,000 barrels annually, derived from two chief sources – city-ground flour and "wharf flour" brought in by boats from country mills in the Tidewater. In 1805, sixteen merchant mills were located within four miles of Baltimore, and fifty within eighteen miles.

Very soon Baltimore passed Philadelphia to become the world's most important center of flour production and of trade in breadstuffs, a leadership it held until well into the 1830's. Its sources of supply were constantly expanded as transportation improved and nearby fields became exhausted. First, grain and flour from the Tidewater region were supplemented by supplies from the slightly higher Piedmont country stretching to the Allegheny foothills, and from up the Susquehanna as far even as the southern tier of counties of central New York State. The incoming grain and flour were floated down the rivers on great "arks," or carried overland as roads and wagons improved. The product of country mills came to be known as "Howard Street" flour, from its place of inspection. With the extension westward of the Baltimore and Ohio Railroad – its first section from Baltimore to Ellicott's Mills was in use from 1830 (Oval, Chapter XII) – the rich grain lands beyond the Alleghenies were tapped, and Baltimore's flour production rose before the Civil War to 800,000 barrels a year, most of it city-ground because it had now become more profitable to ship bulk wheat into the city to be processed by the efficient methods of large-scale milling. But by that time Baltimore, in spite of its great output, had been surpassed as a milling center by new cities nearer the great western grain fields, and had yielded first place as a market to the city of New York.

Richmond became an important merchant-milling center only a little later than Wilmington and Baltimore. When La Rochefoucauld-Liancourt visited the city in 1795, he found only two mills; the James River power canal had just been finished in the preceding year. But there was a vast

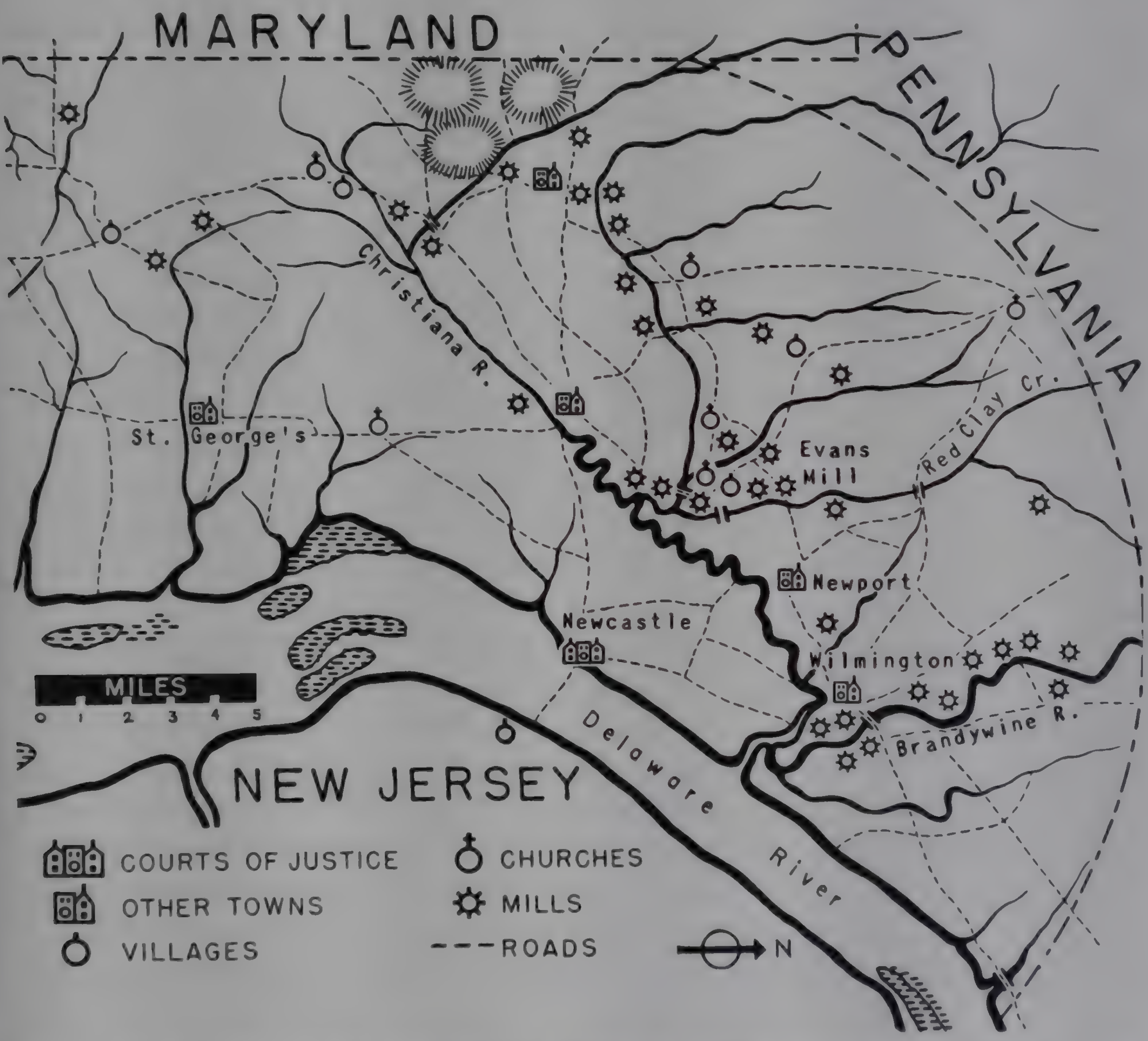

MARYLAND
PENNSYLVANIA
Christiana R.
St. George's
Evans Mill
Red Clay Cr.
Newport
Newcastle
Wilmington
Brandywine R.
Delaware River
NEW JERSEY
MILES
0 1 2 3 4 5
COURTS OF JUSTICE
OTHER TOWNS
VILLAGES
CHURCHES
MILLS
ROADS
N

Figure 69. Mill sites in the Wilmington district, as shown on the Shallus map of 1799 (after Bathe). Evans' mill was located on the west side of Red Clay Creek.

territory adapted to wheat in Virginia, on the uplands between the rivers in the Tidewater and on the Piedmont back of the fall line on which Richmond was located. The trend was shifting away from tobacco, as Roger Atkinson noted in 1770: "We have now got another staple of late years, as it were created, viz., wheat, which will, I believe, in a little time be equal, if not superior to Tobacco – is more certain and which we shall, in a few years, make more in Virginia than all the Province of Pennsylvania put together altho' it is their staple commodity."

Richmond was the natural place of exit for most of Virginia's wheat, and her production grew as transportation facilities opened up more distant fields. Richmond never had many mills – in 1833 there were but three and in 1859 only seven – but its production reached an annual average of 500,000 barrels in the years before the Civil War. Its mills were the largest in the country almost to Minneapolis days: the Gallego mill ground 900 barrels a day at its best, and the Haxall 700 barrels. The quality of Richmond flour, especially from the Haxall mill, was famous, and was held to be superior for the South American trade because of its ability to weather a tropical climate.

Far to the west, across the mountains and beyond the Ohio in the Illinois country, the French had established missions by 1685. It was they who about 1700 introduced bluegrass and white clover into the country west of the Appalachians. The French had so far succeeded in taming the Illinois region that Charlevoix in 1721 prophesied that it would become "the grainery of Louisiana." In 1746, in fact, they did send 100,000 pounds or more of wheat down the river, a portent of vast harvests to come; but the trip down and back took from the end of December to the middle of February. These settlers were almost completely isolated, as were those from the English colonies who pushed across the Alleghenies about 1744, and finally on into Tennessee and Kentucky. A similar isolation prevailed farther north, in western New York, where the fertile Genesee territory was not opened up until some time after the Revolution.

By 1776 many parts of what was to be the United States formed separate, close-knit, flourishing little units, set on the coastal borders of almost self-sufficient hinterlands, and stretching backward into rich but almost unreachable areas. Almost always these settlements were served by their own toll mill. For "the gossip bakehouses" of Pliny's day, pioneer America substituted the church and the mill as places for the exchange of news and ideas; "to mill or to meetin'" went Americans to find out what was going on, and what it meant to be an American. Many American farmers did not spend more than ten dollars a year for outside goods of any description, buying only such nonproduced necessities as salt and nails. Transportation was so expensive that grain was sometimes converted into whisky, a more valuable product of smaller bulk – the origin of today's liquor manufactures in Pennsylvania, Kentucky, and the western parts of Maryland and Virginia. More and more the making of whisky became a merchant operation, and the sale of grain to make it a source of cash.

Except where contacts were possible by water, the difficulties of transportation severely restricted economic relations and cooperation between settlements and, unless something heroic was accomplished, would prevent the opening up of remote areas. Except for settlements on pronounced coastal indentations, like those of New England and the Virginia and Maryland Tidewater and its offshoots, or on riverways like the Connecticut, Hudson, and Delaware, the future of the country depended on the creation of a vast system of inland transportation, either by land or water. The decisive initiative toward solving this problem was taken in the Pennsylvania grain country, under the incentive of its rich wheat production. Once the prototype had been worked out there, it was eagerly copied and adapted elsewhere.

The initial Pennsylvania solution of the American transportation problem comprised two features: first, the Conestoga wagon, later called the prairie schooner, "the finest wagon the world has ever known," which got its name from a little town in Lancaster County situated about sixty miles due west of Philadelphia; and second, the Lancaster Turnpike, which was built to connect the wheat-growing farm country thereabouts with the sea. The wagon came first, for it was being widely used in Pennsylvania from about 1760 and soon became the pride and mainstay of the Pennsylvania back country. Here in 1786, within ten miles of Lancaster, there were eighteen grain mills, sixteen saw mills, one fulling mill, four oil mills, five hemp mills, two boring and grinding mills for gun barrels, besides numerous other enterprises, located in a richly fertile region. The building of better highways began when a private turnpike company was organized in 1792 to construct a toll road between Lancaster and Philadelphia. After initial failures, a hard-surfaced road was built according to the principles of John MacAdam, in which a layer of small stones is compacted into a solid mass on a convex well-drained earthen base. The road was a great success — at one time ten thousand Conestoga wagons ran to Philadelphia from other towns — and the idea of turnpikes was copied in other parts of Pennsylvania and elsewhere, especially in New England and New York. By 1800 Albany was in good road communication with the Genesee Valley to the west of the Finger Lakes, and another important wheat-growing region was made more accessible to the city markets of the Atlantic Coast.

But the wagon trains moved westward throughout the first half of the nineteenth century, far in advance of the slowly expanding turnpike systems. They followed trails cut through forests, over rocks and stumps and through mud holes, laying down saplings side by side over the most impassable stretches to form the bone-breaking "corduroy" roads of the time. They were pressing on to clear and settle the level, potentially rich farm lands of Ohio, Indiana, and Illinois, and then to cross the Mississippi into vast plains where not even forests were an obstacle. Settlements invariably formed around any source of water power, however slight it might be by comparison with the turbulent streams of the more hilly East: mills must be scattered liberally over the roadless country to form centers from which farm communities might radiate.

As a typical example, there was an outcropping of a ledge of limestone that made a waterfall, eight or ten feet high, across a small stream in what is now Madison County, Indiana. This was such an unusual phenomenon that the stream itself was named Fall Creek, and a settlement, called Pendleton, was established around its falls in the early decades of the nineteenth century. The first small grist mill, housed in a log cabin, was built at the falls in 1825, but other and more ambitious structures were added rapidly, until there were flour mills, saw mills, and a woolen mill. Pendleton became a center of trade for the region, and as the rich surrounding farm lands were cleared of the forest, "it was not uncommon to see as high in number as 50 wagons waiting to discharge a load of grain or wool or to receive a grist or load of lumber." As late as the 1840's, this village was so remote that a communal wagon train was dispatched twice a year to Cincinnati, the nearest major trading center, to take out furs, grain, and flour and bring back salt, coffee, cotton goods, medicines, and other things. It was a six-week journey there and back.

Yet the attractions of Pendleton and other nearby settlements in the forest, surrounded as they were by the deep, black soil of an almost flat terrain, were so great that in 1840 a group of millwrights with their families migrated from as far away as North Carolina, many months of travel by wagon train, to build the mills that the new country still needed. One of the authors of this book possesses, as a family heirloom, a record of that difficult and painful journey. The name of one member of the group would eventually be given to the Nordyke-Marmon Company, for many years one of the leading manufacturers of milling machinery in America, and to the once famous Marmon car. Many mills were built around Pendleton, of virgin oak and maple, and some of them operated into the twentieth century. Today with changing times not one of them stands: Fall Creek does not turn a single mill wheel.

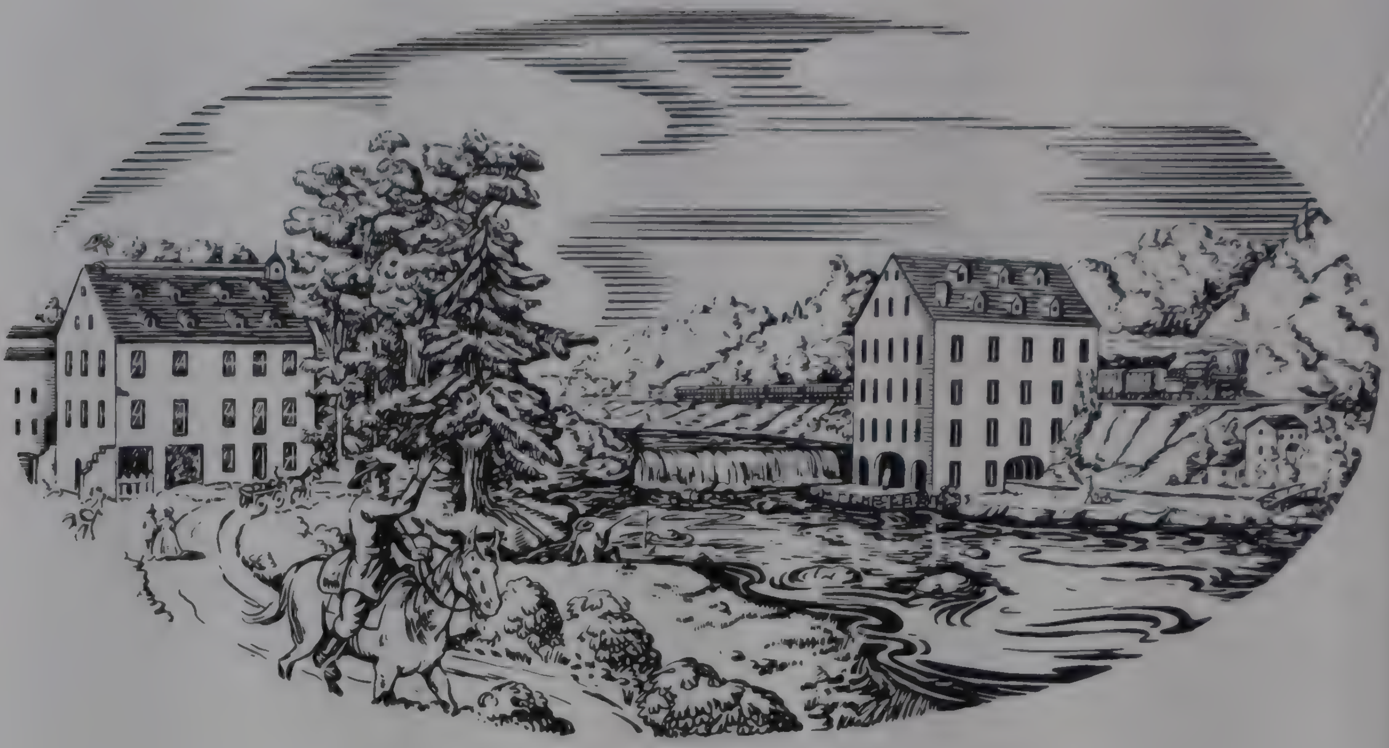
In this way the Midwest was settled. Its immense fertility, responding to the need of grain for the crowding population of the East and for export, was an irresistible magnet. The urge to construct better lines of communication to this rich granary was powerful. There were hordes eager to go west; there were huge crops of grain available there if means could be found to bring them back. Transport by water was easier then than by highway, and although the turnpikes were pushed slowly west, the greatest effort went into the building of canals. Until a canal network had been constructed, some of the products of the West traveled tortuously by road and path over the mountains, while a large volume reached the East by the extremely roundabout natural water route that lay through New Orleans. The Erie Canal, opened in 1825, was overshadowing in its importance and fame, but it was only the major link among many such arteries that eventually gave a large part of the Midwest grain lands a continuous water route to the Hudson River and New York City.

To the canals were soon added railroads, of still greater speed and carrying capacity, and able to operate all the year round instead of being frozen up during the winter months. Here was the kind of land transport the great continental area of the United States had been waiting for. Railroads were built furiously, a close network covering the populous East and long tentacles thrusting farther and farther west until, at last, they would link the Pacific Coast with the Atlantic.

The population too flowed westward, filling every opening section of the broad continent. As they pushed the frontier ahead of them, they poured back toward the Atlantic a mounting flood of the products of a land abounding in homely riches—cattle and hides, coal and ore, above all wheat and corn, an exuberant, democratic confidence and an expanding hope for the destiny of the growing country.

New techniques were needed to handle this abundance, and to serve the new pattern of population that was taking shape. The old, self-sufficient community, more or less isolated from the world and clustered around the mill that ground the flour and meal for its bread, everywhere was being absorbed into larger entities. The railroads laid down the lines of a new gridlike system, fed by better turnpikes from the back countries and linking remote rural areas closely with urban centers of manufacture and distribution. The country was coalescing in larger and larger units that would become in time, and in some phases of its activity at least, a single nationwide unit.

The means of coping with the problems of large-scale production posed by a continental civilization were ready at hand, since Oliver Evans in the last decades of the eighteenth century had created the automatic mill. His achievements were of the first importance in milling, and exerted a powerful influence on the new attitudes toward all manufacture that were coming to maturity in the modern world of Europe as well as of America. They are little known, too, in spite of the important part they played in the Industrial Revolution. It will pay to analyze them in some detail, before we resume the story of the westward movement of the milling industry, and the emergence of the wholly new techniques of production, processing, and distribution which have set the pattern for the world in which we live. In this transformation, Evans' contributions were a decisive factor.



CHAPTER XII

Oliver Evans Invents the Automatic Mill

> He that studies and writes on the improvement of the arts and sciences labours to benefit generations yet unborn, for it is not probable that his contemporaries will pay any attention to him, especially those of his relations, friends and intimates; therefore improvements progress so slowly.
>
> —Oliver Evans

DEMOCRACY became a practical possibility on a huge scale, and not a mere closet dream of idealists, when power machinery was applied to the rich resources of America to produce the necessities of life at low cost for multitudes of people—when the pioneering spirit that had conquered a wild continent was carried over into the productive activities of a mechanized world. The opening up of America took place at exactly the right period of history to make this result possible.

By the seventeenth century, Western man's accumulating experience with power machines was ready to bear rich fruits, at the very time that his vaguely formulated notions of democracy were beginning to seek realization. These movements coalesced and found a new stimulus in America, where freedom depended on mastery of the environment as much as on release from the tyranny of other men. In Europe democracy had

Chapter head oval. Mills on the Patapsco near Ellicott City, about 1850.

meant equal rights—a claim to status in an existing order; in America it meant equal opportunity—an unimpeded chance to carve out one's future in a new world. Americans want equal rights, yes, but they also want more of all the other good things of life; and in subjugating the New World they learned the hard way that they must win this abundance by their own energy and ingenuity.

Thus Americans were fortunate in that they passed directly from the conquest of a continent to the creation of an industrial system. By means of an advancing technology in a richly endowed land, where a rapidly expanding, equalitarian society provided an insatiable market, they were able to make their great contribution to world civilization—an ever increasing productivity under democracy, bettering the conditions of life for millions of people.

America did not initiate the Industrial Revolution: it began in England, in the textile industry, and it was given its great impetus with the introduction of steam power. But in the stratified society of Britain, the grim horrors of the early factory system widened the contrast between the misery of the workers and the luxury of a few. For a long time there, industrial production was not thought of as a means of supplying the needs of the many. It attempted to serve only the small middle and upper classes, without an incentive to expand beyond the needs of this limited market except for export. Even today, industrial workers in Britain and on the Continent are seldom thought of as the principal customers for the goods they make. For instance, the employees of continental factories, even automobile factories, come to their work by trolley car and bicycle—the great parking lots required by American plants are unknown there.

The early textile factories of America were almost as bad as their British counterparts, but in a society where the "upper classes" were a negligible peak in a rising general level of prosperity, it was inevitable that manufacturers should set their sights ultimately on a mass market that must in time include their own and all other workers. They would undertake to serve this mass market by "mass production"—the output of great quantities of identical goods, of standardized quality, at low unit cost, to serve the needs of all. The methods adopted were the introduction of automatic processes, with a decreasing reliance on human muscle and sweat, the adoption of precise controls for the maintenance of quality standards, and increasing attention to research and development. These would be useless without a rising level of earnings keeping pace with increased productivity, and while not all manufacturers cooperated willingly with this latter trend, they all have benefited from its irresistible advance. The process is still far from complete, but already it has made us incomparably the most productive nation in the world, with by far the highest living standard.

It is dramatically appropriate that the first great step in this direction was taken in man's oldest industry, supplying his most basic need—the grinding of grain to make bread. In the late eighteenth century in Oliver Evans' automatic mill, mechanization on a large scale was applied for the first time to providing the cheap goods required by a modern democracy.

Up to the latter part of the eighteenth century, the story of the increasing use of power and the parallel story of technological progress can best be told in terms of the history of milling. Since the introduction of steam power and the rise of innumerable factories full of specialized machinery, milling's leadership in the mechanical arts has diminished; but it has been in the van of progress in a quite different area. When milling techniques and machinery were transformed in the nineteenth century, few of the new processes could be utilized elsewhere. But the manner in which these processes were organized into an almost completely automatic system of manufacture provided a model for the rest of industry: a model which forecast many of our mass-production methods. And it was Oliver Evans who gave milling its decisive impetus in this direction.

Oliver Evans was born near Newport, Delaware, in 1755, and was apprenticed to a wheelwright at the age of sixteen. A typical inventor in the wealth and variety of his creations, at eighteen he had conceived the idea of a high-pressure steam engine with a cylinder of small diameter and long stroke, similar to those later used on locomotives, which he eventually constructed and used for a variety of purposes. At twenty-two he was manufacturing wire teeth for cotton and wool cards and the cards themselves for the textile industry. Later, besides his mill inventions, he created a screw grinder for making a fertilizer out of plaster of Paris, a steam dredge, processes for making artificial ice and for extracting turpentine, a millstone balance, and numerous other devices. He was also the author of two books, *The Young Mill-wright and Miller's Guide* (1795; 15th edition, 1850) and *The Abortion of the Young Steam Engineer's Guide* (1805), as well as numerous articles, pamphlets, and broadsides defending his mill patents or explaining his steam engine.

Thomas Ellicott of the famous Patapsco family, writing in 1795, gives a good description of milling in the Middle Colonies at about the time of Evans' birth: "When I first began the business, mills were at a low ebb in this country; neither burr-stones [French quality millstones], nor rolling-screens [for cleaning the grain] being used; and but few of the best merchant mills had a fan [to cool the ground meal]. Many carried the meal on their backs, and bolted it by hand, even for merchant work; and I have frequently heard, that a little before my beginning the business, it had been customary, in many instances, to have the bolting mill some distance from the grinding mill, and there bolted by hand. It was counted extraordinary when they got their bolting to go by water: after this, fans by hand, and standing-screens [flat sieves worked by power], took place; then burr-stones, rolling-screens, and superfine bolting cloths."

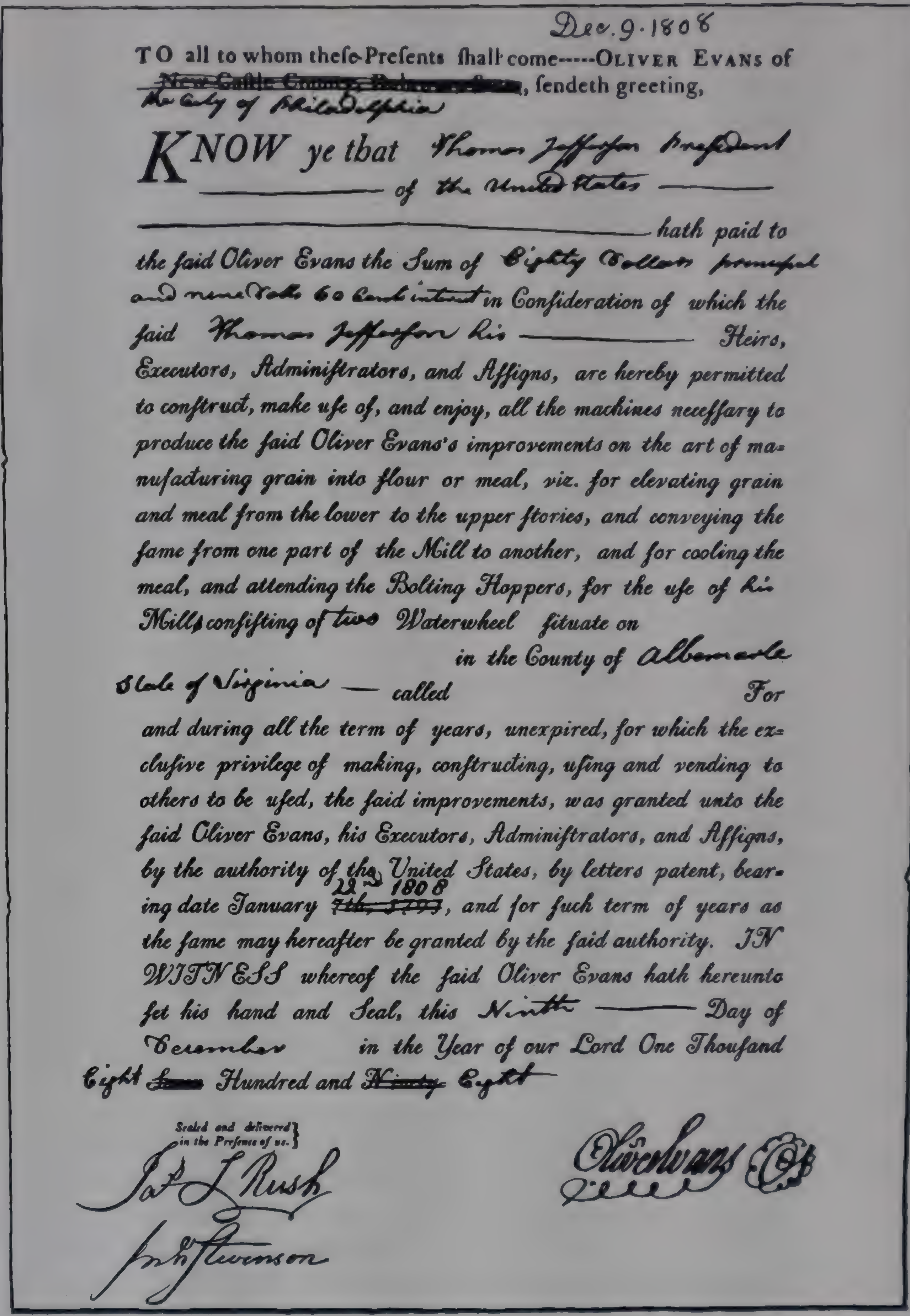
Thus during a little more than a generation, a good many things happened in these mills: it was a lively environment in which Evans grew up. Better millstones were introduced, with improved apparatus for cleaning the wheat and bolting the grind, increased use of the fan, the powering of accessory processes. But in a passage too long to quote Evans makes it clear that most mills were still needlessly dirty and wasteful both of goods and labor, while producing a flour of constantly varying quality. In an ordinary mill he noted that seven tasks were performed by hand – carrying in the wheat, hoisting it, taking it from the granary to the hopper, shoveling the grist into tubs, hoisting them, watching the bolter, and mixing the bolted material – either requiring seven workers or necessitating the stoppage of certain operations while others were being carried on.

In 1782, while still unfamiliar with the details of milling, Evans with two of his brothers contracted to build a mill on Red Clay Creek a few miles north of Wilmington (Figure 69). "I then began to study how I could make the mill exceed all others. . . . I first conceived the great design of applying the power that drives the millstones to perform all the operations which were hitherto effected by manual labour, viz. – from receiving the grain from the wagon or ship until manufactured into superfine flour, ready to be packed into barrels; but being neither millwright nor miller, I had first to ascertain what operations were to be performed by manual labor."

A mill with most of his improvements was in full running order by 1785. Ellicott described the Evans mill as "a curiosity worth the notice of the philosopher and statesman, to see with what harmony the whole machinery works in all their different operations"; but it was easy to regard it in a different light. A pair of Brandywine millers once came to inspect Evans' devices, and found the mill working clean and in perfect order with no one in the building, Evans being busy at the time making hay in a field nearby. Though they were greatly impressed, they were so bewildered by the clatter of strange machinery that they reported the mill to be "a set of rattle-traps."

No single detail of Evans' mill need have surprised anyone familiar with the history of mechanical devices, except possibly the so-called hopper-boy which cooled the ground meal. But there were difficulties nevertheless. Much later, when Evans' patent rights were attacked by millers who had come to realize their value, no less a person than Thomas Jefferson pointed out that all Evans' inventions except the hopper-boy were made of such familiar units as the string of buckets and the Archimedean screw, and therefore denied that he had invented anything. Jefferson had been licensed in 1808 to use Evans' devices (Figure 70). Evans replied:

"Mr. Evans did not invent what he has not patented, nor does he



Dec. 9. 1808

TO all to whom theſe Preſents ſhall come-----OLIVER EVANS of ~~New-Castle County, Delaware State~~, ſendeth greeting, the City of Philadelphia

KNOW ye that Thomas Jefferson President of the United States hath paid to the ſaid Oliver Evans the Sum of Eighty Dollars principal and nine Dolls 60 Cents interest in Conſideration of which the ſaid Thomas Jefferson his Heirs, Executors, Adminiſtrators, and Aſſigns, are hereby permitted to conſtruct, make uſe of, and enjoy, all the machines neceſſary to produce the ſaid Oliver Evans's improvements on the art of manufacturing grain into flour or meal, viz. for elevating grain and meal from the lower to the upper ſtories, and conveying the ſame from one part of the Mill to another, and for cooling the meal, and attending the Bolting Hoppers, for the uſe of his Mills conſiſting of two Waterwheel ſituate on in the County of Albemarle State of Virginia — called For and during all the term of years, unexpired, for which the excluſive privilege of making, conſtructing, uſing and vending to others to be uſed, the ſaid improvements, was granted unto the ſaid Oliver Evans, his Executors, Adminiſtrators, and Aſſigns, by the authority of the United States, by letters patent, bearing date January 22d 1808 ~~7th, 1799~~, and for ſuch term of years as the ſame may hereafter be granted by the ſaid authority. IN WITNESS whereof the ſaid Oliver Evans hath hereunto ſet his hand and Seal, this Ninth Day of December in the Year of our Lord One Thouſand Eight ~~Seven~~ Hundred and ~~Ninety~~ Eight

Sealed and delivered in the Preſence of us.

Jas. J. Rush

Jno. Stevenson

Oliver Evans

Figure 70. License granted to Thomas Jefferson for the installation of Evans' improvements.

claim; his patent being for his improvement in the art and manufacture of flour and not for machines. The string of buckets, Archimedes' screw, the drill plough, are as free as they ever were to the public, and are no improvement in the art or manufacture of flour."

This point was hard to understand in those days, as Jefferson's failure to grasp it shows. Yet it is fundamental, and will help us to see why millers were so slow in availing themselves of the Evans mill: for years he offered the right to install it free to the first miller in each county who would accept it and, aside from Jonathan Ellicott, found no takers. Evans was no impractical inventor; he was thoroughly energetic in pushing his ideas, and quick to take advantage of any opportunity to place them before the public. He once calculated that one of his brothers had traveled about a hundred thousand miles to push his mill. *The Young Mill-wright* is a model of clear and careful, though untutored, presentation; it contains all information necessary to construct an Evans mill, from fundamental physical theory to a bill of materials of the parts needed to build it. Fessenden in 1808 rightly commended Evans for combining theory with practice in presenting the art of milling, and names his book as the first to do so in America. It is withal an ingratiating treatment, utterly without wild claims or extreme statements.

Yet Evans' ideas were so unfamiliar that they were hard to grasp even when clearly put. The complexity of the Evans mill will be immediately apparent from Figure 71, which reproduces with a few clarifications the schematic drawing he arranged to illustrate his improvements. But this schematic design is simplicity itself compared to our redrawing of his plan for an actual mill, shown in Figure 72. All sorts of strange things were going on there, and the mill was fitted with a maze of alternative passages and connections, to allow, as the miller might decide, this, that, or the other operation, all automatic after the proper settings. At the same time, however, we can now see that the fundamental plan was quite simple. Evans lifted the material by water power to the top of the mill as many times as was necessary, and allowed it to pass down by gravity through power-operated machines from floor to floor in logical succession; he conveyed the material horizontally from place to place, as seemed best, so that the machines on each level could be rationally arranged in the mill space. Control and flexibility were arrived at by a free three-dimensional organization of the machines according to the processes for which they were employed. No wonder Evans was not understood: he was not a conventional miller or millwright, but the first thoroughgoing plant engineer.

To understand more clearly what Evans was about, we must run through the elements with which he worked. To the water wheels, millstones, and the other equipment of ordinary mills, about which he had his quota of suggestions, he added his "improvements." Evans nowhere

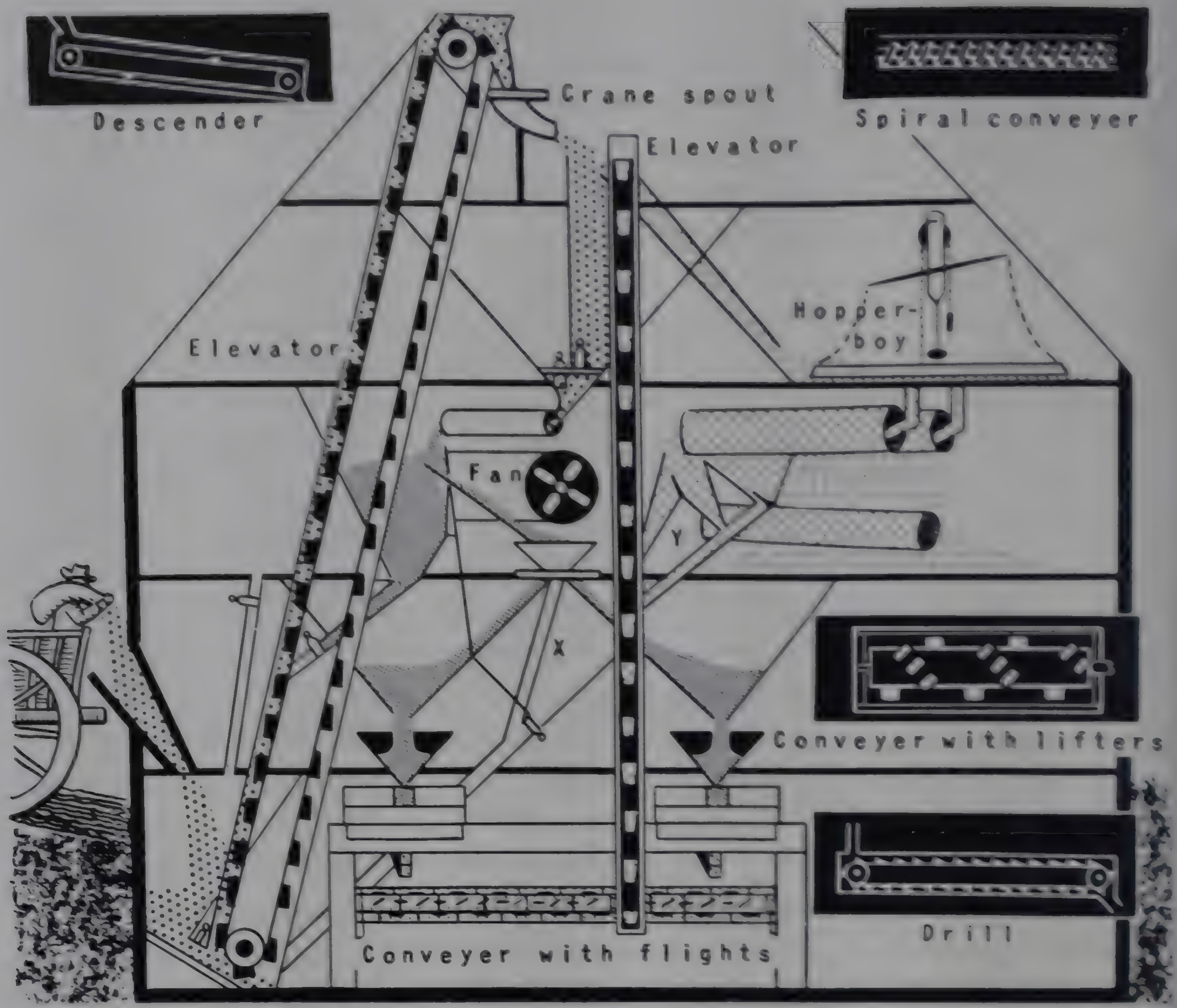


Figure 71. Evans' own schematic plan of his mill "improvements," as given in *The Young Mill-wright*. The inserts show types of conveyer described by Evans. Grain is poured from a wagon into a bin, from which an elevator raises it above a rolling screen for cleaning. The clean grain is delivered to the stones for grinding, whence the meal is carried by conveyer and elevator to the hopper-boy for drying and cooling. Under the hopper-boy are the bolters for separating the various grades of end product.

lists all of them. Not all were patented, and of those patented some were never used; they emerged from his mind in easy abundance. First and most important were the arrangements for transporting materials from place to place: elevators to raise materials, gravity chutes to drop them, conveyers to carry them sideways. Examples of these arrangements, as of the others we shall discuss, will be found in Figures 71 and 72.

At least since Ramelli's day, grain had been hoisted in sacks or tubs by means of a power-driven windlass, but this interfered with grinding by putting temporary heavy loads on the power. With Evans' elevator, which consisted of small buckets on an endless belt, the load was constant and light, and the stone-drive could be set to allow for it. As the buckets passed over a pulley at the top, their contents were delivered to a garner or a machine, or to any one of a number of places according to the setting of a crane spout. These movable spouts were another of Evans' improvements, and he made a liberal use of them. The one labeled in Figure 71 could deliver grain to the rolling screen over the fan for cleaning, as shown; or could divert it into a second hopper to the left, whose "gate" is closed in the figure – Evans used many of these gates; or could send it into garners under the eaves. Sometimes, as at Y in Figure 71, material was delivered to an elevator in the midst of its lift – in this case the overtailings or coarser screenings of the bolters, which could be returned for rebolting by adjusting cutoffs, of which again there were many.

At 29 and 31 in Figure 72 is perhaps Evans' most important single

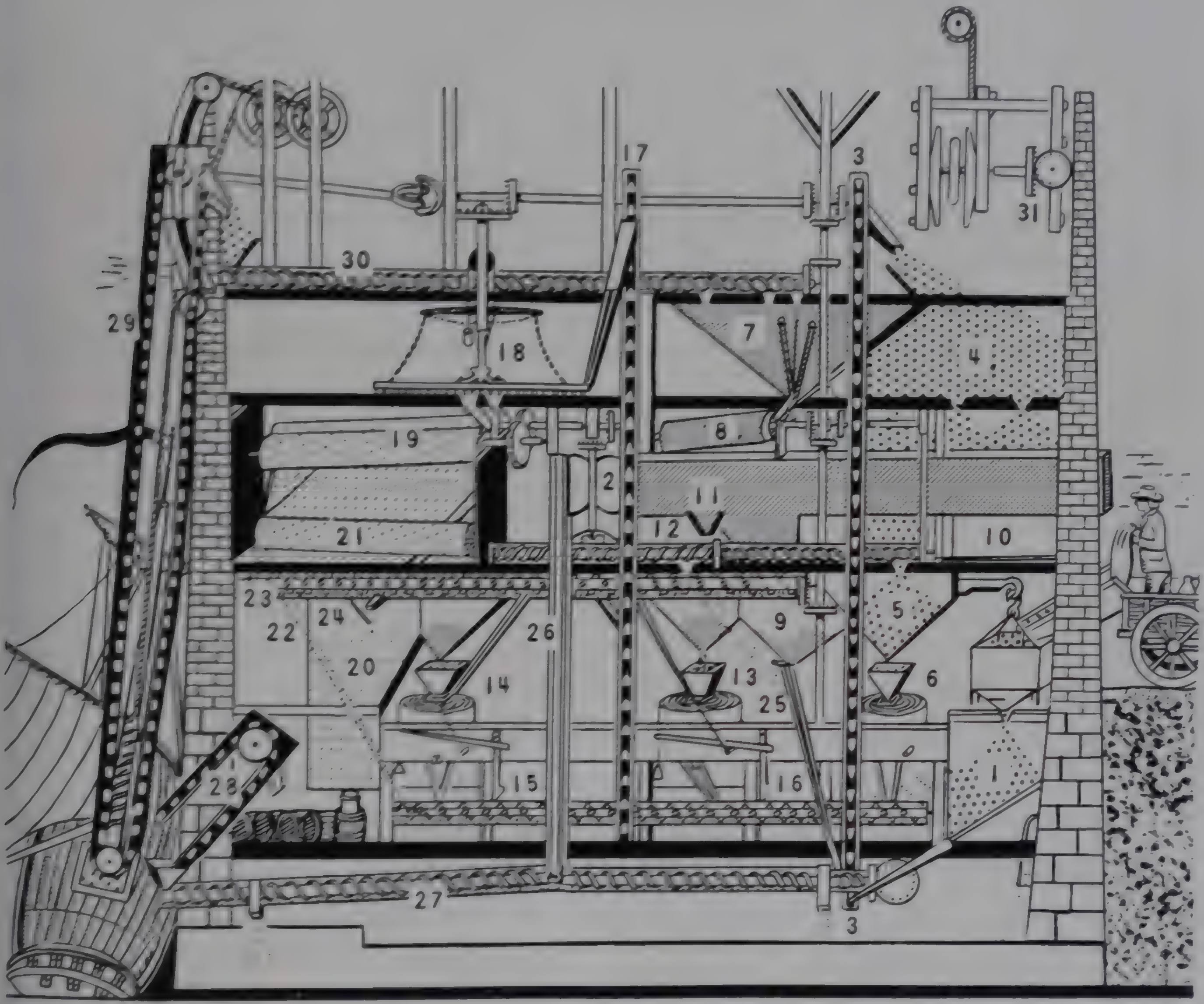


Figure 72. Complete layout, by Ellicott, of a mill utilizing the Evans improvements, equipped to receive grain from wagon or ship. Explanation of numbered items: 1, receiving bin; 2, fan for aspirating grain; 3, 17, 28, 29, elevators; 4, grain garner; 5, 6, hopper and ending stones; 7, grain bin over rolling screen 8; 9, 10, 11, 12, 25, treatment of stock from rolling screen; 13, 14, grinding stones; 15, 16, conveyers for ground stock; 18, hopper-boy; 19–24, bolters, packing-chest, and middlings devices; 26, air passage; 27, 30, conveyers; 29, elevator for unloading ships, with the top shown from a 90° angle at 31.

device, because of its later importance in grain handling – a special elevator for raising grain from a ship. The pulley over which the elevator buckets passed was mounted in a movable slide, and a rope running over two pulley wheels permitted a single man standing below to shift this slide up or down, to control the length of the elevator as the grain in the ship diminished or the tide changed. Although Evans illustrated this device in *The Young Mill-wright* and gave a clear description of its construction, it had little effect on American milling until 1843. It was then resurrected by Joseph Dart of Buffalo, and it immediately permitted a tremendous growth of the Great Lakes grain trade. The Evans grain elevator as brought to life by Dart was an indispensable adjunct to the quantity handling of grain in the middle decades of the nineteenth century.

Evans made gravity the miller's friend instead of his enemy; but to those without eyes to see, the repeated raising of wheat and meal in elevators only to have these materials pass down again through the mill must have seemed a frenzy of machinery for its own sake. Why elevate the material so often? And why not just carry it, the way everyone else was doing? These questions seemed to be posers, especially in view of the careful handling and adjustment Evans' machinery required. Yet Evans' thinking was prophetic, and today industrial operations include means for transporting materials and parts wherever these can be used advantageously.

In addition to his elevators, Evans had a number of arrangements for moving materials in a generally horizontal direction as our figures show. He tells us that the most important, the spiral or screw conveyer, had been thought of first by Jonathan Ellicott, who used it only to move the bolted flour from both ends of the bolting chest to a hole in the middle, through which it fell into a storage space. Because the prevalent grinding methods produced a damp, hot grind which was likely to clog the conveyer, Evans used the spiral conveyer only to move unground grain. While in his conveyer, the grain was partially cleaned by a blast of air from a fan.

None of Evans' actual mill designs made any use of the drill, one of his inventions in which a number of "rakes" on a belt drew material along the bottom of a case to an exit; or of the descender, in which the material was originally supposed to move by rotating an endless belt by its own weight – in the second edition of *The Young Mill-wright* he wisely added the observation "it may be put in motion by water [that is, by mill power] and is preferred." Giedion calls this the prototype of the endless belt so often used in the modern factory, but the two arrangements are only superficially similar. However, Evans' extensive use of conveyers was soon followed not only in mills – where modern conveyers are usually of the belt or screw type – but also in plants of many other kinds.

Of all his mill inventions Evans was proudest of his hopper-boy for cooling the ground meal. In his day American millers used the old, American or flat-grind system, in which the wheat passed between the millstones but once for grinding, with the stones set close together. The meal left the stones damp and hot, with the bran broken into fine bits, and it would clog the cloths if not cooled before bolting. It was usually shoveled onto the floor for drying, and then picked up in the same manner and carried to the bolters. "The whole of the meal loft was little enough to cool the meal on." In Evans' system, a conveyer with flights or lifters received the meal as it left the stones, and carried it to an elevator for delivery to the hopper-boy. This was a perpendicular shaft rotating about four times a minute, around the lower end of which an arm with downward projecting flights was loosely fitted. The meal delivered by a spout from the elevator to the outer end of the arm would first be spread by the flights around the circle of rotation for cooling, and then slowly gathered toward the center, where it would fall through a hole into the bolter. By adjusting a counterweight the cooling time allowed while the meal was moved toward the hole could be lengthened or shortened.

In his 1808 patent specifications Evans laid even greater stress than previously on the necessity of drying the ground meal, and proposed to heat it with air from a stove or kiln drier while it was in the conveyer, on the way to the elevator. His description of the process informs us that millers by then were accustomed to kiln-dry their grain—a practice of which Evans did not approve: he considered that it made the skin of the berry so brittle that it pulverized and mixed with the flour. Evans' kiln drier was never much used, although his hopper-boy was often installed in mills using the old flat-grind system. It passed out with the rise of the so-called New Process of high grinding in the mid-nineteenth century.

Evans usually submitted his wheat to a preliminary cleaning, before delivering it to the rolling screen for the customary separation of particles of different sizes. He did this by sending it through millstones set far enough apart to rub and clean the grain without grinding it into meal—a process he did not originate, since "ending stones" to clean the grain were in common use in his day. If the grain arrived by wagon, it was let into the mill, weighed, and given a first cleaning by an air blast while being dropped into the receiving bin.

Evans also cleaned by means of a rolling screen consisting of two cylinders of sieve wire, the inner cylinder with meshes large enough to pass the wheat and retain everything larger, the outer cylinder with smaller meshes so that the wheat was tailed over while all small stuff passed through. The French had used devices of this kind, but they had been hand operated. In this cleaning process the rejected material was carried away, while the good wheat from the tail end of the outer cylinder dropped into a wind tube, where it fell at least three feet through a strong air current (11, Figure 72). Good grain fell directly down into a conveyer for transmission to the grinding stones; light wheat particles were blown into a screening garner whence they could be returned for rescreening whenever desired; chaff and other light stuff were blown into a bin; very light dust was carried out of the building.

Evans' arrangements for bolting the ground meal were elaborate and expensive for his day. According to the set of a dividing board at the tail end of the bolters, the greater part of the material served to them was passed through the silk as fine flour, and dropped into a packing chest (20, Figure 72) ready for barreling. Here the first hand-work in Evans' mill was necessary. The rest of the grind was served into a reel for further grading into "tail flour, the middling stuff, etc."

The term *middlings* must be cleared up; from now on we shall meet it increasingly, for middlings became the problem of modern milling. Flour, of course, consists of substantially pure endosperm – the starchy interior of the wheat berry – in a finely divided state. Middlings consist of this same floury matter in larger, though often as a matter of fact quite small, particles, either with or without adhering bits of bran. By "tail flour" Evans probably meant fine middlings, approaching flour in the size and purity of the particles. Whatever the size and degree of purity of these middlings, they were for long a problem, because while they contain valuable endosperm, it exists in them in a condition not salable as first-quality flour.

Evans himself made no use of flat screens or sieves in his mills, although wire-lined "shaking sieves" are mentioned by Thomas Ellicott in the conclusion which he added to Evans' *The Young Mill-wright*: "They are of considerable use in country mills, to sift indian meal, separating it into several degrees of fineness if required, and take the hulls out of buckwheat meal, that are apt to cut the bolting-cloth, and the dust out of the grain, if rubbed before ground; and are sometimes used to clean wheat and screenings instead of rolling screens." Since these sieves were shaken by mill power and were probably set up one over the other in tiers, we have here the faint first beginnings of the modern plansifter. But no more than three or four gradings were attempted, in contrast to the many achieved today by batteries of sifters.

Evans worked in an environment keenly interested in bolting. In the great French Encyclopedia which began publication in 1751, it had been stated that bolting offers too many special problems and involves too many complicated machines to be included in a flour mill. For a long period, too, bakers preferred to do their own bolting. Though separate establishments were not uncommon in eighteenth-century America, as the quotation from Ellicott on page 160 indicates, it became more and more the rule in this country for grinding and sifting to be carried on under the same roof. The millers of our Middle Colonies became distinguished not only for the

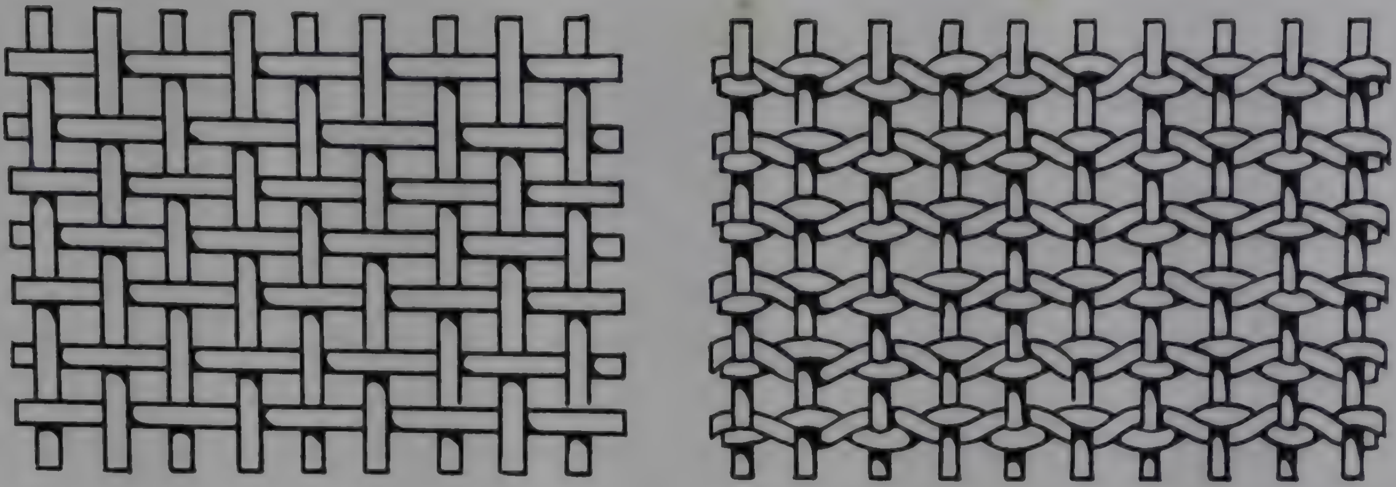


Figure 73. Bolting-cloth weaves. At the left, the regular weave, as used for inferior cloth and for cloth of very fine mesh. At the right, the twisted weave which prevents the meshes from spreading.

quality of their millstones, often imported from France, but for the excellence of their bolting arrangements; even in the late seventeenth century they had superior facilities for bolting export flour. In his *Travels*, published about 1799, La Rochefoucauld-Liancourt noted that the Brandywine millers were sifting through silk, rather than the usual linen or wool. Many preferred wire screening, however, as being more durable, in spite of its tendency to rust.

During the period of unrest in Europe from 1789 to 1815, the Dutch fish-net factories began to supply a superior cloth with twisted threads to keep the meshes from spreading (Figure 73). In 1832 Henry Bodmer applied this idea to silk and greatly improved its manufacture, which he discovered could best be carried on in a suitably damp section of Switzerland. Among his largest customers from the start were American millers. Whereas the Dutch had been able to supply the twisted weave only up to Number 8 cloth (about 88 threads to the inch), Bodmer's workers were soon making covers with 125 or more threads to the inch.

Evans so greatly extended the use of the fan in milling that he included it in his 1790 patent, although fans had long been in use; Ellicott called it "the Dutch fan." The main previous use of the fan had been to clean the throughs of the rolling screen, a process that Evans improved, as we have seen. In his enlarged use of air currents we have a background from which the purifier could eventually emerge. The first steps in this direction were taken abroad, but they were described by Benoît, the very person who translated *The Young Mill-wright* into French, so that Evans' influence can probably be discerned here also.

After the initial period of reluctance, Evans' devices were rapidly introduced even into small mills everywhere in the United States. Abroad, however, the change to the completely mechanized mill was made more gradually, and not as a general rule until the 1870's and 80's. Figure 74

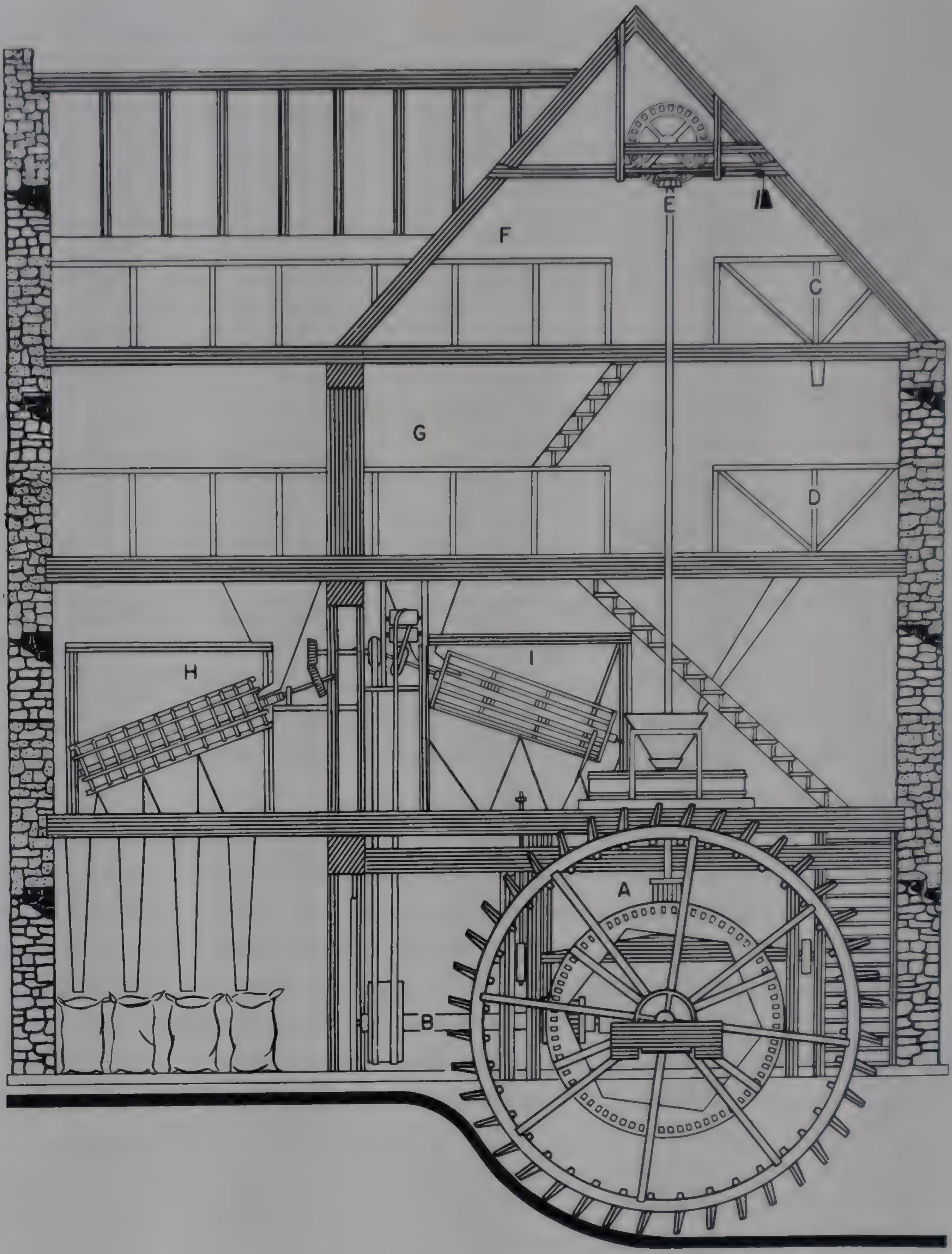


Figure 74. Design for a small breast-type water mill, by Andrew Gray of England (1806). In contrast to most American mills of this period, mill power was used only to run the millstones and the bolters (H and I), and to power a rope and pulley for hauling up the grain. A, the lantern gear which transmits power to the millstones, and through them to the pulley gear at E. B, the shaft which transmits power to the bolters. C and D, storage garners. F and G, cooling stands: this was an Old-Process mill and ground low, heating the meal, but was equipped neither with Evans' hopper-boy nor with his elevators and conveyers. The hot meal was carried upstairs to these tables; when cooled, it was shoveled into the hoppers of the bolters. The wheat was cleaned by mill-powered flat sieves, ending stones, and a fan in another part of the mill.

shows the grinding and bolting departments of a typical small English water mill of the early nineteenth century, planned by the well-known millwright Andrew Gray. Though neatly designed, this mill is without Evans' elevators and conveyers, and is less well equipped for grinding than most American mills of the same date. In the differences between Gray's and Evans' mills we can see the higher value set upon human labor in the American environment, as compared to the English. We have here both an effect of pioneer conditions and an augury of increased democratic opportunity in the United States.

A mill equipped with the Evans improvements could be run by one man for each twenty barrels of flour produced per day, whereas ordinary mills required one man for each ten barrels. Taking six different ordinary parcels of wheat—white and red, clean and dirty, uncontaminated and mixed with garlic or cockle—Evans obtained the following average results:

	Percentage
Superfine flour	64.33
Tail flour, middlings	7.33
Ship stuff	3.37
Shorts, bran	17.57
Screenings and loss	7.40

The screenings were excessive because some of the parcels were dirty; for the two cleanest samples this figure averaged 2.28 per cent. The shorts included wheat germ, bran, and a small amount of floury material; ship stuff was composed of coarser middlings. Superfine flour extractions ranged from 59.5 to 68.5 per cent. Evans' average of 64 per cent fine flour agrees well with Thomas Ellicott's figures, and with Evans' own early claims, that from two to three pounds more flour to the bushel could be obtained his way than by the old method. This gave Evans an advantage of from 3 to 5 per cent, as most millers were getting about 60 per cent extraction of top-grade flour by the old method. To achieve his result, Evans reground the middlings and other tailings from his bolters; but he still had left some 10 per cent of tail flour, middlings, and ship stuff in which he could not separate the bran from the flour or grind the endosperm particles fine enough. This 10 per cent could be sold only as second-rate flour. In addition his superfine flour cannot have been as pure as good flours are today. Future improvements in milling would revolve around efforts to improve the quality of the clearest part of the grind, on the one hand, and on the recovery of more good flour from the 10 per cent of middlings and other similar materials that Evans could not separate.

There was another approach to this problem of the middlings on which Evans had sound ideas, although he failed to carry them through to their logical conclusion. Evans preferred to have his millstones rotate more slowly than most millers—at about 100 revolutions a minute for a five-foot stone, as compared to the customary 150 or more. He also thought that undue pressure was responsible for poor flour: "It is not the degree of fineness that destroys the life of the flour, but the degree of pressure applied on it in grinding. Flour may be reduced to the greatest degree of fineness, without injuring the quality; provided, it be done with sharp clean stones, and little pressure."

These were good ideas, as French advocates of *la mouture économique* had been proving tentatively from at least the sixteenth century. In the so-called French system, there were a number of grindings in succession, each with its bolting, the overs of each bolting being used as the material for the next grinding. The stones were separated more widely than usual for the first grinding, and were brought closer together for each step in the series: they rotated 50 or 60 times to the minute, or about half as fast as Evans recommended. In periods of dearth the French millers ground their materials as many as seven times; some regularly made five grades of flour, including three called white, as well as three grades of bran.

Beckmann, an early and not always reliable author, tells us that extractions after the introduction of the French system ranged from 77 to 81 per cent, as compared to yields of from 33 to 38 per cent before. Figure 75 represents this situation schematically in highly simplified form. The bolting might be done by mill power, or more frequently by hand-operated machines (Figure 76). Extractions arrived at by the French system cannot easily be compared in detail with those achieved by other methods, since the divisions between grades of product follow different lines. It was not unusual, however, for French millers to extract 66 per cent "white flour" in three grades, with perhaps a little more than half being of the highest quality.

The most important thing about the French system was the idea of dividing the quite simple processes of grinding and bolting into stages in which each class of materials of approximately the same size and nature received special treatment, rather than all being treated together as parts of a conglomerate mixture. This notion never occurred to Evans; in fact, he consciously used certain machines simultaneously for more than a single purpose, as when middlings were sent back to be reground along with whole berries. Even the French failed to follow the practice consistently; they were interested more in increasing their salable extractions than in improving the art of milling. The time was now ripe for a more theoretical approach to milling than they were inclined to attempt.

The acceptance of Evans' ideas themselves depended on the growth of a more theoretical disposition among millers in America. It must be admitted that the most important feature of his improvements – their great flexibility – was arrived at by a too great reliance on the judgment of those who would have to operate his mills. Writing of his mill inventions

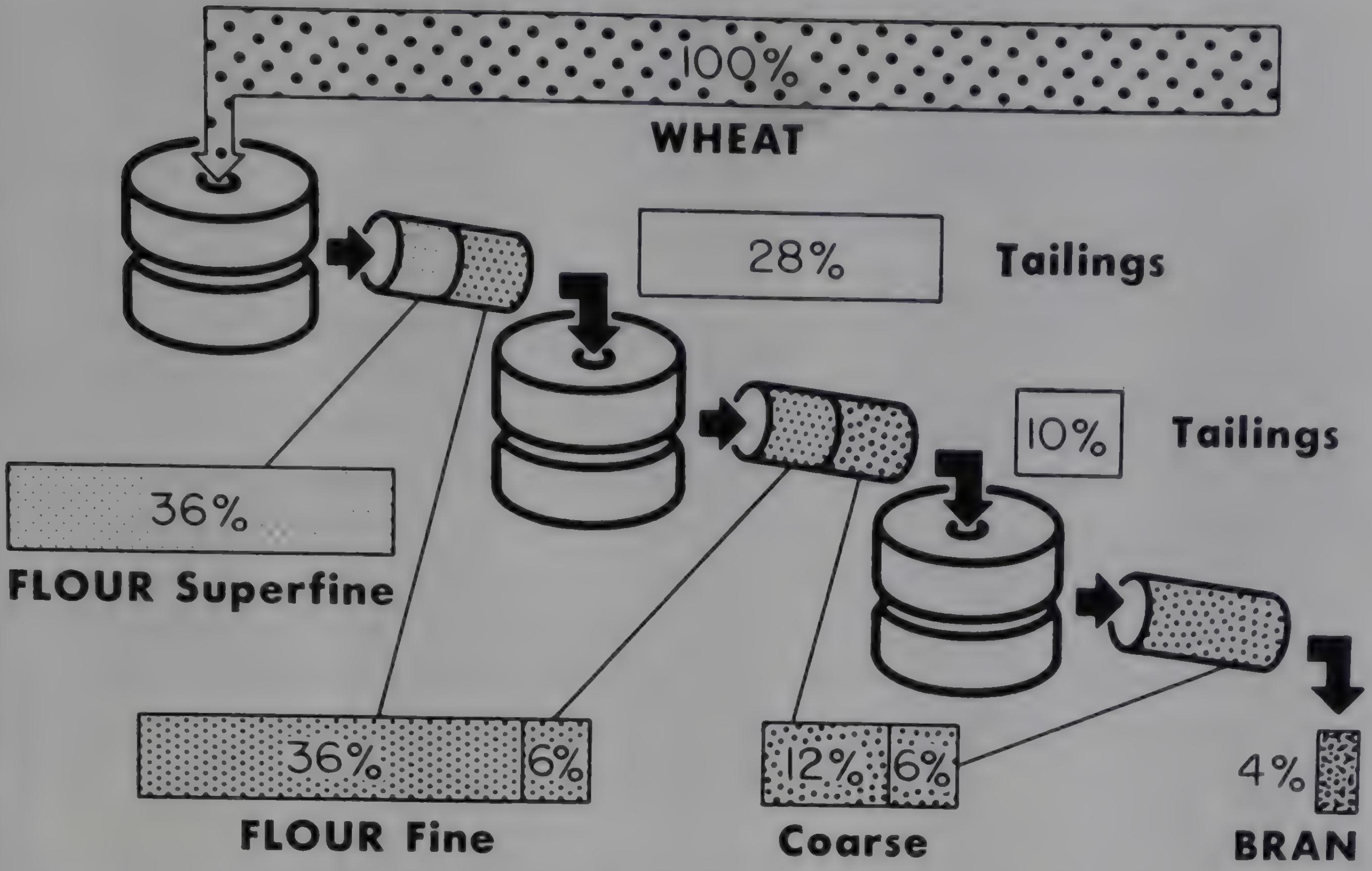

100%
WHEAT
28%
Tailings
10%
Tailings
36%
FLOUR Superfine
36%
6%
FLOUR Fine
12%
6%
Coarse
4%
BRAN

Figure 75. Generalized diagram of a French-Process mill giving two grades of flour and four of end products. The first pair of stones is set rather far apart and yields two grades of flour from the finely meshed bolter to which the meal is served. The tailings from this bolter are reground on stones set more closely together; at this bolting more second-grade flour is obtained. There is a third grinding and bolting of the tailings from the second grind.

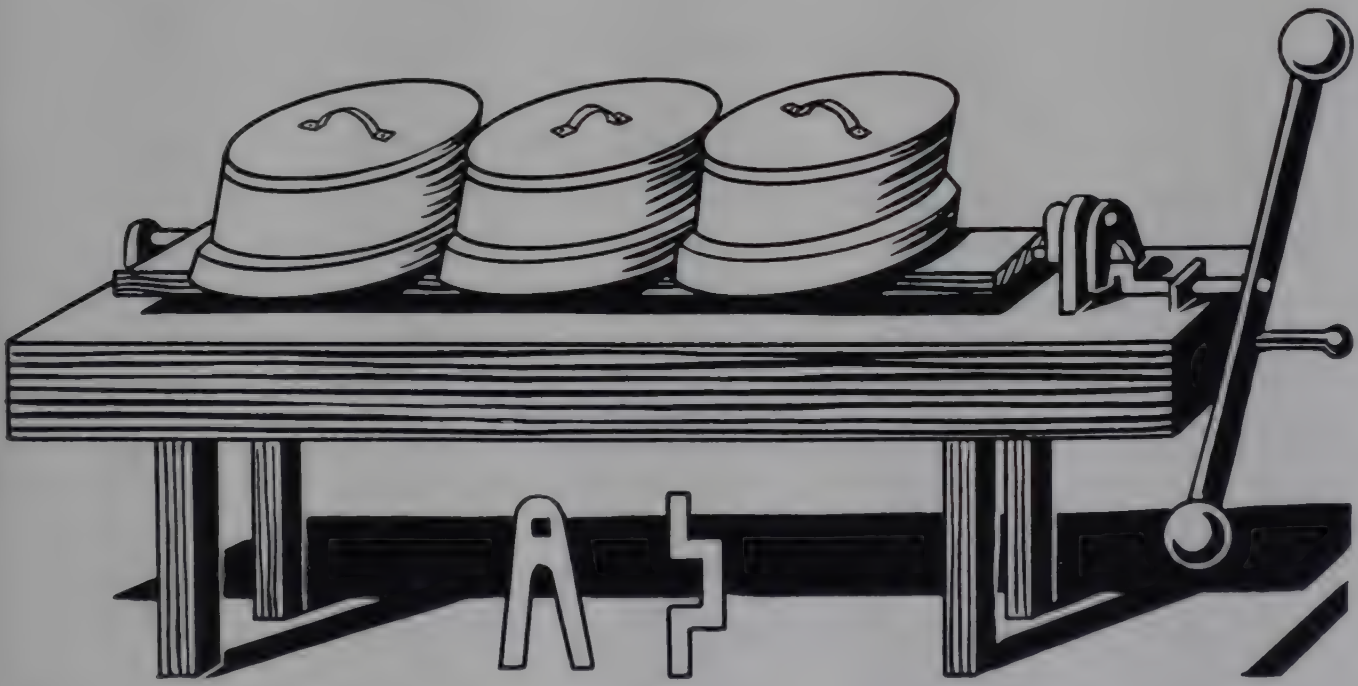


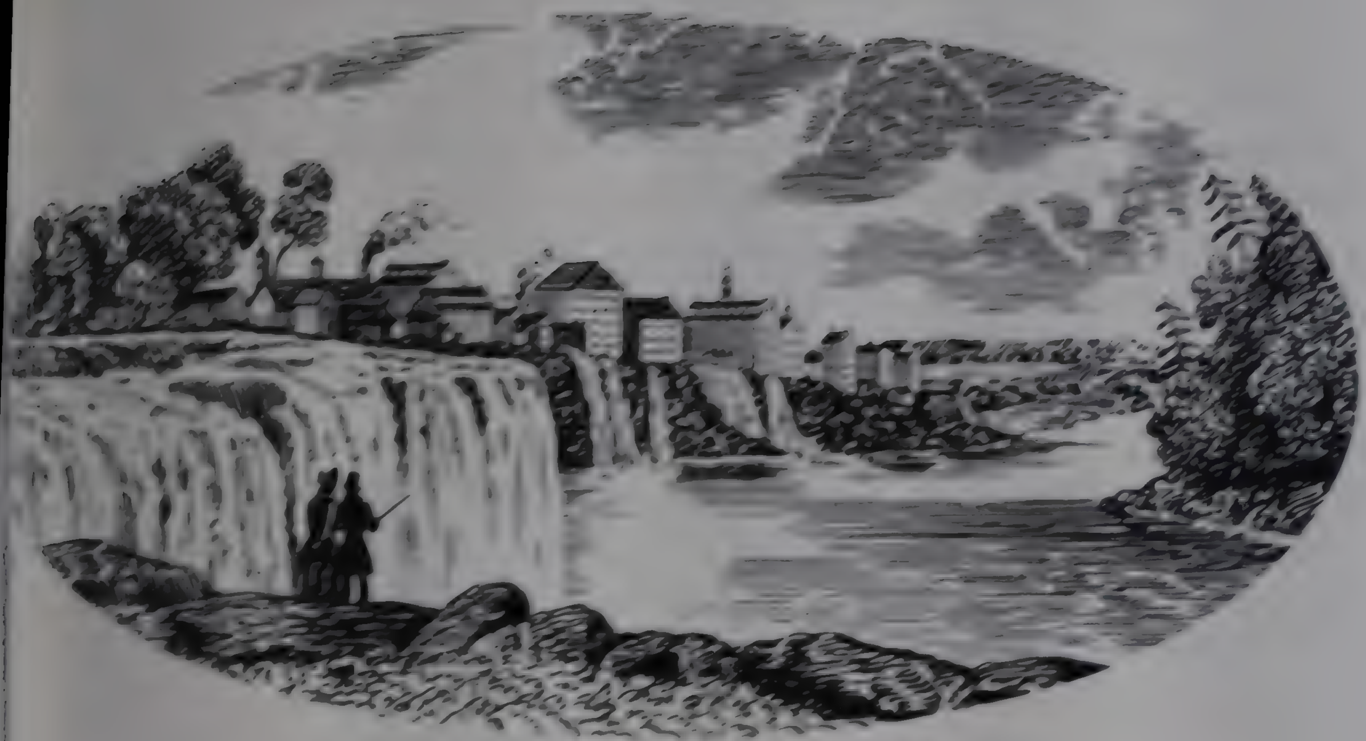
Figure 76. French multiple sieves, worked by hand, from a 1721 patent. Two of the parts needed to effect the agitation are shown under the table.

in 1818, six years before his death, when a good deal of the battle had be won, Evans said: "Before they perfectly succeeded, he had many alte tions to make, great difficulties to surmount; and though the result exceede his expectation, the introduction of them into general use was extreme laborious, and much more difficult than any other incident that had, hither to, attended its progress."

It required what Evans called a miller of scientific turn to adopt h methods completely, adapting them to varying conditions. In the current state of machine-tool manufacture, then highly imperfect, his machine required the most careful adjustment. They ran with little or no attenti when working perfectly; but they needed informed and careful anticip tory attention to yield satisfactory results. To appreciate and use the Eva methods, a miller must be a little of both engineer and scientist, a type har to find, at home or abroad, in Evans' day. Although many in the Baltimo and Wilmington region were already engaged in large-scale mercha activity, few were as alert as the Ellicotts, who already by 1790 were usi the Evans improvements.

When Robert Leslie went to England shortly thereafter to introdu Evans' ideas, he was finally forced to report: "The milling business is don on a very different plan from what it is in America, and on so small a sca that the saving of labour to any one owner of a Mill, would be no obje and from my own observation I believe it is true, for I think that ni tenths of all the wheat in England, is ground by little footy wind mil that do not look worth 20 pound each, but the number of them is so gre as to be able to do all the business, but the owners of them would soon jog on, in the old way, than give five shillings for all the improvements the world." In 1800, only a few years later, while English millers we getting about 17 per cent animal feed from their operations – a figure ve close to that averaged by Evans – they were extracting only about 55 p cent of fine household flour as compared with his 64 per cent of superfi

Toward the end of his life Evans had the satisfaction of seeing his ide increasingly accepted, including not only his milling improvements b his steam engine. The two were, in fact, sometimes combined, as at Pit burgh in 1808, where Evans erected a steam flour mill equipped to opera three run of stones. By 1812 Evans had ten of his engines in use, of fr 10 to 25 horsepower and warranted to grind 240 bushels of grain in twel hours or to saw 5,000 feet of boards. As Evans' ideas were adopted t trend toward merchant milling on a large scale, already very strong, w given a great impetus that has been maintained to the present day. T capacity of Evans' mechanisms for quantity production, their higher ec and their ready susceptibility to improvement all tended to increase t scale on which milling must operate to gain a maximum econo advantage.



CHAPTER XIII

Westward Ho!

In the early Nineteenth Century, the United States spread out from east to west like a page in the history of society.

—Frederick Jackson Turner

It is not how much grain can be raised on an acre, but how much from one hand or man, the land being nothing in comparison with labor.

—Faux (1836)

HROUGHOUT history it has been the rule that expansion of grain lands s been life-giving in a realistic sense—it has enabled more people to e and to live more abundantly. But nowhere in the world has this truth n demonstrated so dramatically as in the United States.

Here a fringe of sparse settlements along the Atlantic Seaboard, ching tentatively through the forests toward the Appalachian Mountains, w in a century into a wide, massive belt spanning the continent, tined to become incomparably the richest nation in the world and the rld's most impressive demonstration of democracy. In this growth our

pter *head oval.* The Falls of the Genesee at Rochester in 1838. The mills on wn's Race are shown in the background.

central farm lands have been and still are a decisive factor: without the abundant supply of basic foodstuffs – bread and meat – which their enormous grain crops made available to all the people, no such growth of territory and population, no such rise in well-being, would have been possible.

Evans' mechanization of milling arrived at a critical moment to become one of the three indispensable keys which would unlock the riches of these grain lands and distribute them throughout the country. Improvements and inventions in transportation, the progressive mechanization of agriculture, and large-scale automatic milling formed a triad which, acting together, would first make the fertile soil yield foodstuffs in greater volume than the world had ever seen before and then place these foodstuffs at the service of the whole population from coast to coast. There have been many other contributions to the wealth of the nation, none of them to be discounted; but all other productive activities have hinged on the abundant feeding of the people which these three nineteenth-century developments have made possible.

Throughout the early decades of the nineteenth century the country was working feverishly to extend itself westward, and at the same time to overcome the handicaps which increased with every mile of distance the settlers placed between themselves and the Atlantic Seaboard. Inland locations not on navigable water were isolated from one another and from metropolitan markets. They had to make do with what was available in the immediate vicinity and they could contribute little to the general wealth of the nation. Thus wheat which sold for 25 cents a bushel in Illinois in 1825 was worth 80 cents in Petersburg, Virginia, and $1.25 in Charleston, South Carolina.

On the other hand, we have seen how the construction of the Philadelphia-Lancaster toll road in the late eighteenth century had increased the prosperity of Philadelphia while at the same time it made Lancaster, its other terminus, the leading inland city of the United States, although its population was only 4,292 in 1800. This object lesson was not wasted on the rest of the country: it led immediately to the construction of hundreds of other turnpikes, chiefly in Pennsylvania, New York, and New England. The Cumberland Road was the most important of the free national highways; begun in 1811, by 1818 it had been completed from Cumberland, at the head of navigation on the Potomac, to Wheeling, on the Ohio (Figure 77). Thus by linking two great water routes, it allowed the products of the Ohio Valley to flow into the Middle Atlantic region.

In the meantime river navigation by steam power had begun on the Ohio in 1811, and by 1820 sixty steamers were working up and down the Ohio and Mississippi and even the Missouri. In 1823 a steam vessel reached the Falls of St. Anthony on the upper Mississippi, where Minneap-

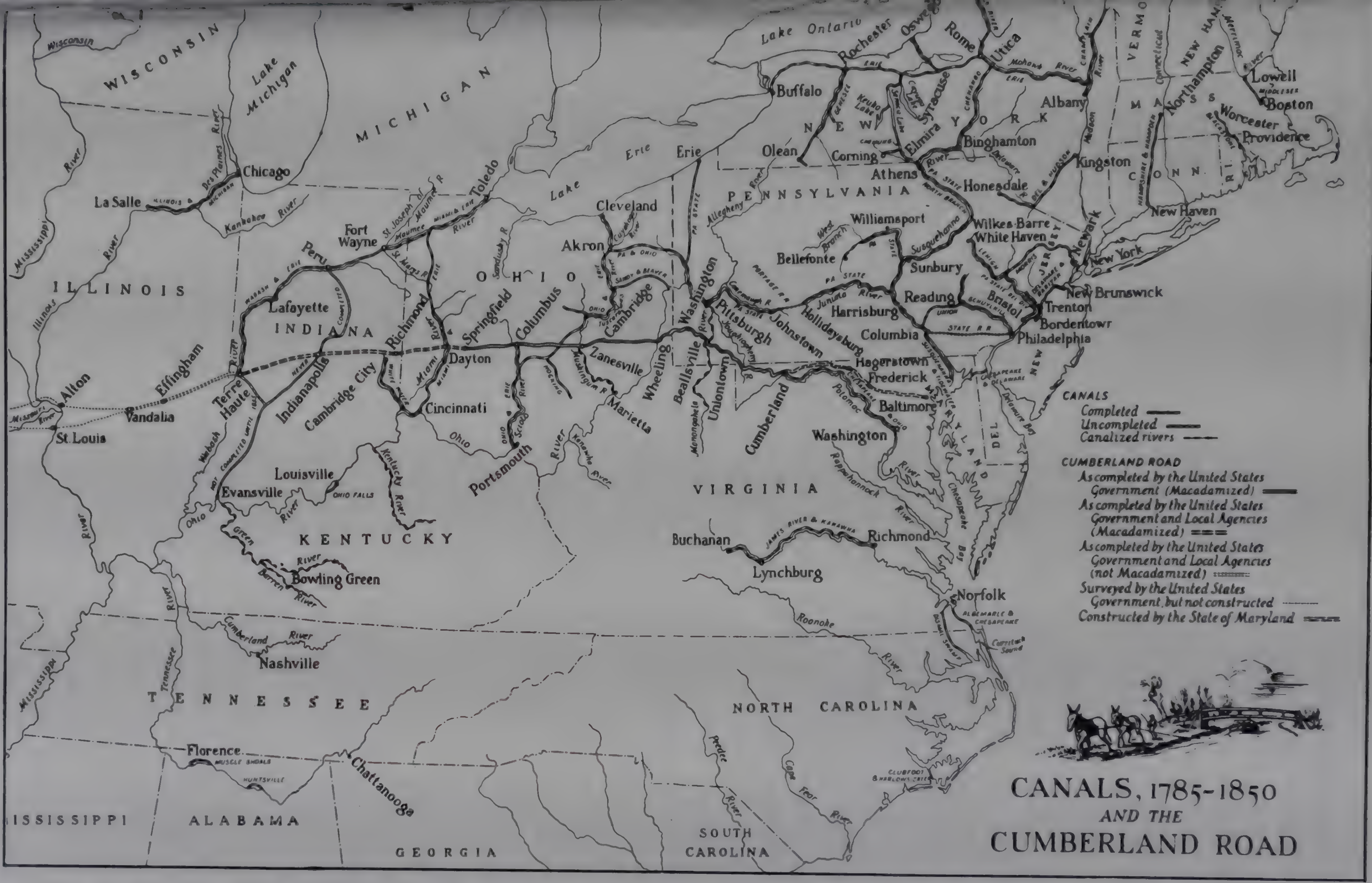

CANALS, 1785-1850
AND THE
CUMBERLAND ROAD
CANALS
Completed
Uncompleted
Canalized rivers
CUMBERLAND ROAD
As completed by the United States Government (Macadamized)
As completed by the United States Government and Local Agencies (Macadamized)
As completed by the United States Government and Local Agencies (not Macadamized)
Surveyed by the United States Government, but not constructed
Constructed by the State of Maryland
WISCONSIN
MICHIGAN
ILLINOIS
INDIANA
OHIO
PENNSYLVANIA
NEW YORK
VERMONT
NEW HAMPSHIRE
MASS
CONN.
R. I.
NEW JERSEY
DEL
MARYLAND
VIRGINIA
KENTUCKY
TENNESSEE
NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
ALABAMA
MISSISSIPPI
Lake Michigan
Lake Erie
Lake Ontario
Chicago
La Salle
Fort Wayne
Peru
Lafayette
Toledo
Richmond
Springfield
Dayton
Columbus
Cincinnati
Portsmouth
Cleveland
Akron
Cambridge
Zanesville
Marietta
Wheeling
Erie
Washington
Bealllsville
Uniontown
Pittsburgh
Johnstown
Hollidaysburg
Cumberland
Hagerstown
Frederick
Baltimore
Washington
Harrisburg
Columbia
Reading
Bristol
Trenton
Bordentown
Philadelphia
New Brunswick
New York
Newark
Wilkes-Barre
White Haven
Sunbury
Williamsport
Bellefonte
Athens
Honesdale
Kingston
New Haven
Northampton
Worcester
Providence
Lowell
Boston
Albany
Utica
Rome
Oswego
Syracuse
Rochester
Buffalo
Olean
Corning
Elmira
Binghamton
Terre Haute
Indianapolis
Cambridge City
Effingham
Vandalia
Alton
St. Louis
Evansville
Louisville
Bowling Green
Nashville
Florence
Chattanooga
Buchanan
Lynchburg
Richmond
Norfolk
Ohio
Mississippi River
Illinois River
Wabash
Kentucky River
Green River
Barren River
Cumberland River
Tennessee
James River & Kanawha
Rappahannock River
Potomac
Chesapeake Bay
Delaware Bay
Roanoke River
Cape Fear River
Pedee River
Monongahela
Youghiogheny
Susquehanna
Juniata River
Hudson
Mohawk River
Erie
Wabash & Erie
Miami
Scioto River
Muskingum R.
Kanawha River
Sandusky R.
Maumee
St. Joseph R.
Kankakee River
Des Plaines River
Illinois & Michigan
Ohio Falls
Muscle Shoals
Huntsville
Dismal Swamp
Albemarle & Chesapeake
Currituck Sound
Clubfoot & Harlows Creek
State R.R.
Portage R.R.
PA State
Union
Schuylkill
Lehigh
Morris
Delaware & Raritan
Chesapeake & Delaware
Chesapeake & Ohio
Genesee
Chenango
Champlain
Delaware & Hudson
Hampshire & Hampden
Blackstone
Middlesex
Merrimac River
Connecticut

Figure 77. America's canal system, 1785–1850, and the Cumberland Road. From the 30's to the 50's the canals of the Middle West were especially effective in connecting the interior with the route by way of the Great Lakes and the Erie Canal to New York City and the East. Thereafter the railroads increasingly supplanted canals, focusing on the same outlets at Chicago, Toledo, and Cleveland, but also providing more efficient trans-Allegheny highways than Pennsylvania's portage route to Pittsburgh. (Map reprinted from *Atlas of American History*, edited by James Truslow Adams and R. V. Coleman; copyright 1943 by Charles Scribner's Sons.)

olis is now located. The number of steamers on the Mississippi had grown to a thousand by 1850, and New Orleans handled more shipping than New York City, while the tonnage of Pittsburgh on the Ohio was greater than that of Boston, Philadelphia, and Charleston combined. This great Mississippi River system with its many branches offered its valleys a continuous, though long and tortuous, route for shipments to the Atlantic Coast and Europe, and New Orleans' receipts of flour and corn rose steadily until in 1843–1845 they averaged 625,000 barrels of flour and 888,000 bushels of corn.

At first, most river products came from Ohio, which had been settled in the eighteenth century by people who entered the country along the Ohio River, and which had been admitted to statehood in 1802. The increase of the state in population was phenomenal even for our Middle West, the number of people rising from a little over 45,000 in 1800 to more than a million and a half in 1840. By 1820 the state had emerged from the frontier stage and stood in urgent need of outlets for farm products. Until the 1830's the faraway mouth of the Mississippi proved a better exit for grain grown along the river than Lake Erie or any overland route to cities east of the Alleghenies. Shipments consisted principally of tobacco, flour, whisky, and pork – the three last were ways of shipping grain in concentrated form. The trade grew steadily, until in 1822 goods to the value of $3,000,000 passed the falls of the Ohio at Louisville on the way to New Orleans: pork, $1,000,000; flour, $900,000; tobacco, $600,000; whisky, $500,000.

By 1840, however, when Ohio led the states in wheat production, her shipments through New Orleans were decreasing. In 1845 that city received only 220,000 barrels of flour from Ohio as compared with 700,000 barrels sent to Lake Erie ports. New Orleans by this time was getting most of her grain and flour from new wheat territories in the valley of the Missouri, centering on St. Louis.

The new routes from the West to the East which displaced the Mississippi highway were largely man-made. The Great Lakes, of course, were an important link in the chain, but natural watercourses flowing into the Lakes from the south were insignificant, and Niagara Falls interposed a formidable obstacle to passage by way of the St. Lawrence, which in addition was roundabout and ran through Canada. But the valley of the Mohawk stretched westward from the Hudson at Albany, and its entire rise from Albany to Lake Erie was only 568 feet in 360 miles, with only one steep ascent of 62 feet at the Niagara escarpment. Along this route New York started to build the Erie Canal in 1817: the first section, between Rome and Utica, was completed in 1819, and the entire Canal in 1825.

The Erie Canal was a brilliant success even before it was finished. On October 29, 1822, the first shipment of flour left Rochester for Little Falls, whence it was carried overland and by river to Albany and New York City. In 1823, with the eastern part of the Canal completed, Rochester shipped 10,000 barrels of flour to Albany. In 1826 her 7 merchant mills, with 24 run of stones, and utilizing many of the Evans improvements, were sending about one third of a production of 150,000 barrels east over the Canal.

All of Rochester's flour until about 1830 was manufactured from local wheat, since Buffalo was not yet receiving imports from up the Lakes. The valley of the Genesee, which had been a famous Five Nations corn-growing region, now became an international wheat granary. The Niagara escarpment crosses the Genesee at the site of Rochester, dropping the river's level 228 feet in a little over a mile and a half, just as it creates the great falls of the Niagara River about forty miles to the west. Only the smaller falls of the Genesee were used by the first settlers, but after Brown's Race had been built around the 96-foot main falls early in the nineteenth century, it became possible to tap this magnificent power source (Oval, Chapter XIII). By 1835 Rochester had 18 merchant mills, with 78 run of stones and a production of 460,000 barrels. The 1836 Albany inspections of state-derived flour, not including western flour received at Buffalo, totaled 936,630 barrels, and the Genesee region had far surpassed the Baltimore district in milling activity.

By this time western wheat was reaching Buffalo to swell the local supply. Buffalo had been laid out into city lots in 1803–1804 on behalf of its Dutch banker-owners, the Holland Company, by Joseph Ellicott, a member of the famous Bucks County and Maryland milling family who had assisted in planning the national capital some years earlier. He had a lively belief in this site at the head of Lake Erie; on being asked once whether New Amsterdam, as Buffalo was then called, would ever be larger than Batavia, the small inland town from which he had been instructed to do business, he replied, "This is to ask whether the local office of the Holland Company or the power of God Almighty is the greater." Until 1822, however, Buffalo was a port without a harbor; in 1816, according to Samuel Wilkeson, who more than any other was responsible for building the town's first breakwater, "no craft larger than a canoe could enter Buffalo Creek." It was Wilkeson's breakwater which determined the Canal commissioners to make Buffalo the western terminus of the Erie Canal. A feverish expansion ensued. When Mrs. Frances Trollope visited the town in 1828 on her famous tour, she wrote, ". . . all the buildings have the appearance of having been run up in a hurry, though everything has an air of great pretensions; there are porticos, columns, domes and colonnades, but all in wood."

For a short time practically all of Buffalo's Canal traffic ran westward. In 1827 eastbound freight was so scarce "that it was difficult to get a full boat-load, although the canal boats were then of light tonnage," and this in spite of the fact that the Canal had lowered the freight charge from Buffalo to New York City from about $100 to $10 a ton and the time in transit from twenty to eight days. In 1828, 2,500 bushels of wheat from Maumee, Ohio, heralded the flood to come. In the three following years Buffalo's total receipts of wheat and flour together soared to 8,000, 180,000, and 250,000 bushels, all from lake ports in Ohio. By 1836 the receipts had reached 500,000 bushels, and included a small shipment from Grand Haven on Lake Michigan – the first from beyond Lake Erie. By 1838 Buffalo was receiving more breadstuff imports than New Orleans. In the meantime the tonnage of ships on the Lakes had grown from 2,449 in 1825 to 16,300 in 1830; by 1834 Lake Erie alone had 30,168 tons.

During the 1836–1845 decade Buffalo received the equivalent of nearly 42,000,000 bushels of wheat from the West, of which about two thirds had been processed into flour at the source. During the next decade, along with a tremendous increase in shipments, the proportions were almost exactly reversed: of approximately 175,000,000 bushels of wheat and flour received, about 114,000,000 bushels were grain.

The shift, with its powerful effects on the milling industry of upper New York State, occurred largely because the problem of transferring the golden flow of grain from ship to shore had been solved by Joseph Dart. In his own words, "The universal method of transfer was to raise the grain from the hold of the vessel, in barrels, by tackle and block and carry it into the warehouse in bags or baskets, on men's shoulders. . . . The most that could be accomplished in a day, with a full set of hands, was to transfer some eighteen hundred or two thousand bushels, and this only when the weather was fair. Everything was at a stand in bad weather. . . . I believed that I could build a warehouse, of large capacity for storage with an adjustable elevator and conveyors, to be worked by steam; and so arranged as to transfer grain from vessels to boats or bins with cheapness and despatch."

A grain elevator worked by mill power had been tried at Rochester in 1828, and another worked by horses at Buffalo about ten years later. Neither had been effective enough to encourage imitation. The most significant phrase in Dart's account is "to be worked by steam." Buffalo was on the lake shore, not an ideal water-power site such as Rochester, and in 1843 steam had not yet been generally adopted as a power source in the milling industry. Even twenty-seven years later, only two sevenths of the power used in milling was supplied by steam engines. Thus Dart's use of steam was an important step in the emancipation of the milling industry and grain handling in general from confinement to streams and waterfalls. In time it would lead to the building of storage elevators throughout the grain country without regard to the availability of water power.

In its first season Dart's elevator handled 229,260 bushels of grain.

Dart always gave full credit for the basic idea to Oliver Evans, whose similar elevator adapted to raising grain from ships is shown in Figure 72. The only difference, actually, was that Dart raised grain for storage and not for grinding.

It was not until 1847 that a second elevator was erected at Buffalo. Another was installed the following year at Chicago. By 1865 Buffalo had twenty-nine elevators, capable of handling more grain in a day than had been transferred in a year before the first elevator was constructed. The steam shovel was also invented at Buffalo in 1864, for moving grain in a vessel's hold to within reach of the elevator, and speeded up the unloading operation still further. Today, air suction has replaced the elevator in many locations, though thousands of warehouse elevators are still in use.

Bearing in mind that the Erie Canal was completed in the mid-1820's, its influence in the building of the West is very evident in the following figures of population growth:

	1800	*1810*	*1820*	*1830*	*1840*
Indiana	5,641	24,520	147,178	343,031	685,866
Illinois		12,282	55,162	157,445	476,183
Michigan		4,762	8,765	31,639	212,267

In 1825 Canal passengers traveling westward averaged 300 weekly; in 1829 the figure had risen to 3,000. As early as 1827 no fewer than 982 lake vessels entered and left the port of Buffalo. In 1830, 15,000 settlers arrived at Detroit, nearly all of whom had come by way of Buffalo and were bound for places farther on. During June of 1836 "a careful estimate by a citizen showed that one wagon left Detroit every five minutes during the twelve hours of daylight." By 1845 most of the counties in New York State itself were losing population under the growing urge to move west, while the drain on New England had already been substantial.

But even with transportation improving, the swift opening up of our vast western prairies would have been impossible without better agricultural implements. The flatness and loose soil of these lands, once the thick grass cover had been plowed up, and their general freedom from stones, made them especially adaptable to more wholesale methods of cultivation than the world had yet seen. Between 1800 and 1830, 124 plow patents were filed in Washington, including the 1814 and 1819 patents of Jethro Wood, in which the working parts of the plow were cast of interlocking pieces, so that single units could be replaced as needed. By 1830 the cast-iron plow was in general use, and in 1864 riding plows were introduced on a commercial scale. By 1880 the Patent Office had granted 6,686 plow patents.

In reaping, the long-handled scythe had largely replaced the short-handled sickle in the eighteenth century, and the scythe had been improved through the addition of the grain cradle, to catch the grain and lay it in a neat windrow. It took a clever, strong man to swing a grain cradle, but the job of collecting the grain was greatly shortened. Thus matters stood until 1833 and 1834, when Obed Hussey and Cyrus Hall McCormick independently obtained patents for horse-drawn, mechanical reapers. In twenty-five years McCormick sold over 23,000 of his machines. It has been claimed that the reaper moved the frontier westward at the rate of thirty miles a year. Later came the harvester, which at first needed additional workers to bind the grain into sheaves (1850–1851), but from the late 70's, first the wire binder and then the twine binder supplanted these workers. Planting, harrowing, and threshing implements were also improved.

Finally, about 1880, the steam-powered machine to head, thresh, clean, and bag the grain came into use. These threshing machines usually were purchased by "companies" of farmers, and operated on a cooperative basis: all members of the "company" would go from farm to farm in turn, threshing the entire wheat crop of each farm in a day and lightening the work with many hands. "Threshing day" and the "threshers' dinner" that accompanied it became a famous institution on thousands of Midwest farms.

By 1880 four fifths of the American wheat crop was machine-reaped, although cradles for reaping and flails for threshing were still used on small, hilly farms in some parts of the East in the early years of the twentieth century. Rogin estimates that, with the new methods, the time required to plant, grow, harvest, and thresh one acre of wheat, which took from 61.1 to 81.3 hours at the beginning of the nineteenth century, was reduced to from 2.1 to 3.4 hours toward its end. This was an increase in man-hour output not approached during that period in any other industry.

The improved cast-iron plow and the reaper came into use just as western settlers began to enter the smaller open prairies in the 1830's, and proved absolutely indispensable when the great timberless stretches were reached a few years later. A thick, matted coating of grass covered the earth with a heavy sod that sometimes would yield only to six or more yoke of oxen, but within two or three years of breaking, this soil gave rich crops. With land so plentiful, there was every inducement always to plant more, so that ripe grain was often left standing in the fields for want of time to harvest it, even when reapers were available.

As the West rapidly developed, the pull of the Erie Canal proved overpowering. Although most of the settlers north of the Ohio River had come from the South, including Kentucky and Tennessee, the country more and more began to look for its prosperity toward Chicago and the other Lake ports, and therefore toward New York City rather than New Orleans. Roads and canals were built to strengthen connections with the Great Lakes and the East (Figure 77): in Ohio by 1832 a canal joining Cleveland on Lake Erie with Portsmouth on the Ohio River had doubled the value of wheat in central Ohio; Indiana built a canal from Toledo at the western end of

Lake Erie through Fort Wayne to Terre Haute on the Wabash, and by 1855 it was extended to the Ohio River at Evansville; Chicago was joined to the Illinois River, to open up the central part of Illinois. Whereas in 1845 Chicago shipped but 133,000 bushels of wheat, in 1848, after the opening of the Illinois Canal, the figure had risen to 1,066,000 bushels. These canals connected their territories by continuous water route, via the Great Lakes and the Erie Canal, with the Hudson and the Atlantic Seaboard. The Erie Canal, by completing this bond, exerted the deciding influence which held even the states immediately south of the Ohio in the Union when the Civil War divided the country.

As the golden flow of grain poured eastward through Buffalo's elevators, the city grew and prospered. Grain receipts, which had reached two million bushels in 1841, touched 20 in 1852, 60 in 1861, 100 in 1880, and 200 for the first time in 1896. With little water power and without a nearby supply of coal for generating steam, Buffalo did little milling during the early part of this period. Until Niagara's water power was harnessed to generate electricity, Buffalo was handicapped industrially, but transportation and the grain trade made her rich.

In the Genesee Valley, however, and indeed throughout central New York, at least as far east as Syracuse and Oswego, milling continued a headlong expansion during the first half of the nineteenth century. At Rochester, as everywhere when merchant milling gets into full swing, the number of mills in operation declined as total production grew; merchant millers have always striven for the economies of more complete mechanization and increased capacity. The twenty-two mills of 1851 had become eighteen by 1877, but thanks to increased application of Evans' ideas and the introduction of New-Process milling, which will be discussed in the next chapter, their average size was much larger—the Excelsior and Whitney mills alone produced nearly 600,000 barrels of flour a year, or four times as much as seven mills in 1826, and one-third more than eighteen mills in 1835.

In a desperate effort to get enough wheat to supply their needs, Rochester millers in 1835 had imported 100,000 bushels of grain from Canada in spite of the 20 per cent duty. But every year Buffalo's receipts from our own West increased: in 1840 they equalled about 30 per cent of the entire New York crop, and by 1850 over 70 per cent. In that year also, for the first time since the Genesee wheat came into full production, New York grew more corn than wheat and her dairy products were worth a million dollars more than her wheat. The flow of wheat from fresh lands in the West was forcing the Genesee farmers into new activities, and eventually the Genesee and Finger Lakes region was incorporated into the milkshed of New York City. In spite of these ominous changes, New York State still led the country in flour production, which at that time in value of product was the nation's most important industry processing any raw material. New York held the lead until it passed to Minnesota in 1890.

Into New York City poured not only the flour of Rochester and many other upstate points—in 1847 little Oswego on Lake Ontario had the country's largest mill, of 1,200 barrels daily capacity—but also the flour of western districts as their output exceeded local needs. Although it held only third place among the country's flour markets in 1820, by 1822 the opening of the middle section of the Canal enabled New York City to outstrip Philadelphia. By 1830 she was also well ahead of Baltimore as a flour market, and had become the leading center of international trade in breadstuffs. Her population almost doubled between 1820 and 1830, and for the first time she became America's largest city.

In those days the trade in flour was highly speculative; millers shipped their product to New York City without knowing what price they might receive for it. During the hard times of the late 30's, foreign exports were cut in half. Even after exports recovered and advanced to new highs in the early 40's, prices were low for a number of years. The repeal of the English corn laws in 1846 led to a very considerable increase in the importation of American flour—from about one million dollars annually in the years preceding to about six million dollars in the first years thereafter. But until the 70's, none of the inland millers engaged in direct international trade; they sold their flour through New York City exporters, who shipped it to large London houses on consignment.

The market primacy of New York City was augmented still further by the building of railroads. The first American public railroad was a thirteen-mile section of the Baltimore and Ohio built in 1830 to connect Baltimore with Ellicott's Mills, the famous Patapsco milling center. The road had been planned by Baltimore merchants to connect their city with the rich Ohio country, and this eventually it did; but it was not long before New York City was also well served by railroads.

The second railroad built in America, in 1831, paralleled a short stretch of the Erie Canal from Albany to Schenectady, and by 1843 had been extended to Buffalo. The first great trunk line in the country, the Erie system completed in 1851, threaded its way across the fertile counties of southern New York to tap at Dunkirk, on Lake Erie, and soon at Buffalo, the market that was filling the barges of the Erie Canal. With the completion of a railroad from Albany to New York City in 1853, the great port became the terminus of two lines from Buffalo, corresponding to the New York Central and the Erie of today. All these early roads reveal the basic influence of the flour and grain trade in plotting the first railway routes.

Pennsylvania attempted in 1835 to compete with the Erie Canal by building a broken-backed canal-and-railroad system from Philadelphia to Pittsburgh, with a thirty-six-mile portage by stationary engines up inclined planes over the mountains, and in 1846 she commissioned the Pennsylvania Railroad to build a rail line paralleling this project. But the New York City market was too well established and too favorably situated to be overtaken. Our railroad mileage more than tripled during each decade between 1840 and 1860, growing from 2,818 to 30,600 miles during that time.

Nearly one third of this 1860 mileage lay within the borders of Ohio, Indiana, Illinois, Michigan, and Wisconsin, and made the region still more of a vast economic hinterland for New York City, although it swiftly produced many smaller but rich centers of its own. From the late 60's the railroads of New York State began to overtake the Canal in volume of traffic. Although no tolls were charged on the Canal after 1882, and although its shipments continued to rise to a peak of over 4,500,000 tons in 1889, in that same year rail shipments permanently passed Canal shipments. The railroads were faster, their switch lines gave them greater flexibility, and they could run the year round, whereas the Canal was often closed by ice for months in the winter.

Figures 78 and 79 compare the distribution of population and of wheat growing in the United States in 1840 and 1860. As new regions in the West were opened up, wheat became the first surplus crop of nearly every pioneer settlement north of about the Thirty-Sixth Parallel, and remained in strong production throughout the period covered. In Wisconsin, for example, wheat production increased twentyfold, from 212,000 bushels in 1839 to 4,286,000 bushels in ten years, while the population was increasing only half as fast. In 1860 this state produced two bushels of wheat for every bushel of corn. Along with Illinois and Indiana to the south, Wisconsin by 1860 had far surpassed Pennsylvania and New York in wheat grown; these three states, in fact, with Ohio, ranked in the order named as the chief centers of American production, although in all of them except Wisconsin four or five times more corn than wheat was being grown. To the south, in Missouri, the nineteen mills of St. Louis ground nearly 500,000 barrels of flour in 1851; five years later this region was grinding twice as much. After the Civil War and until the rise of Minneapolis about 1880, St. Louis shared market leadership in breadstuffs with New York City. Not even California remained out of the picture; by 1855 she was growing an ample surplus of wheat, had large flour mills, and was seeking ways to market her flour on the Atlantic Seaboard.

By 1860 the first phase in the westward migration of wheat production and milling in the United States was completed, and the newer parts of our country beyond even western New York State had won a clear victory over the East in everything except the marketing of the product. Since that time the center of wheat production of the United States has continued to move westward (Figure 79). The milling industry moved with wheat production; the Atlantic states from New York to Virginia ground 65 per

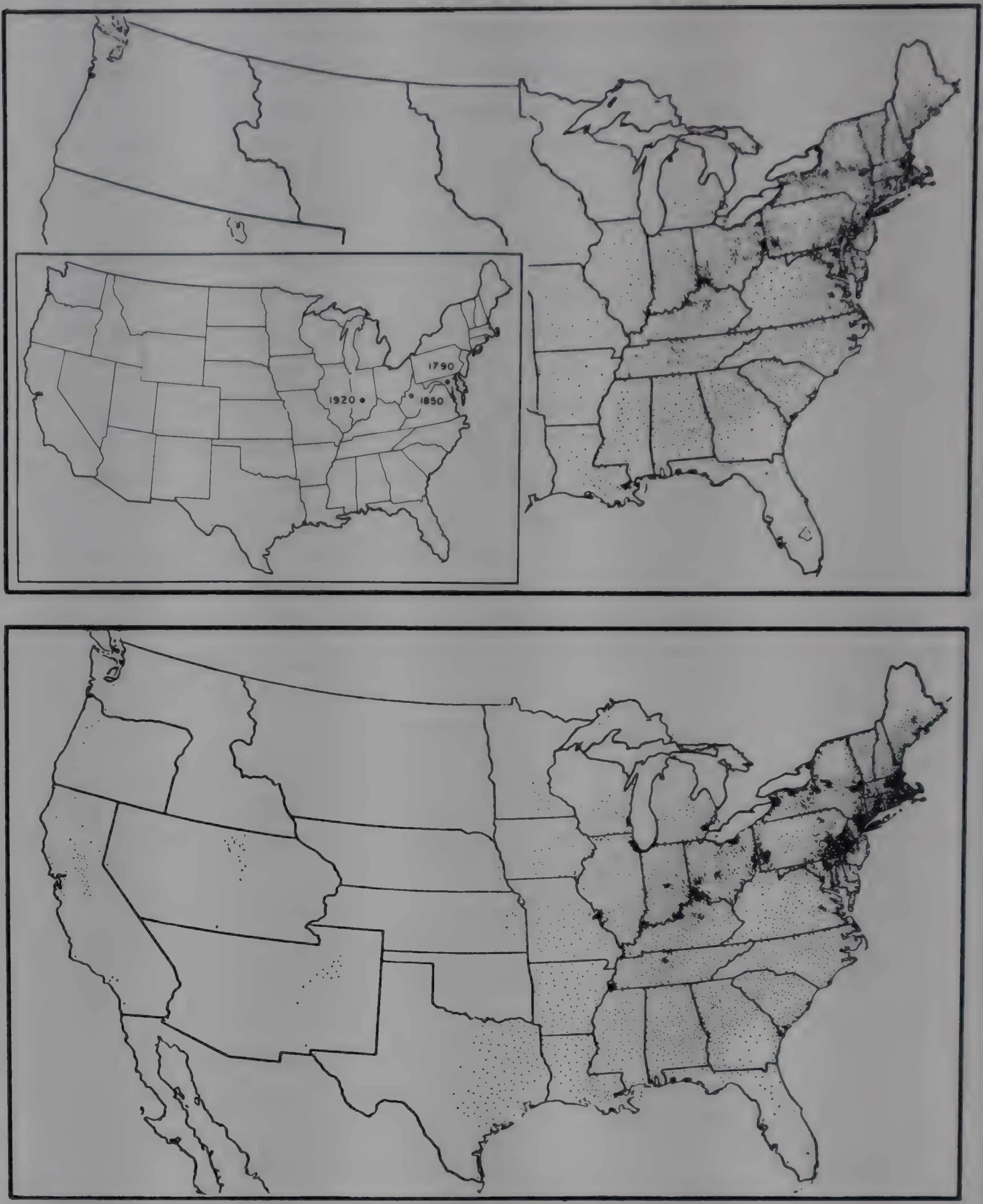


Figure 78. Distribution of population in the United States in 1840 (above) and in 1860 (below). Each dot represents 5,000 persons. On the 1840 map note the already very considerable population in eastern Ohio, on the borders of the Ohio River, and along the Erie Canal in central upstate New York – exactly the western regions that were producing considerable quantities of wheat, as shown on Figure 79. On the 1860 map notice how the former regions of concentration have spread, and how the Mississippi Valley is now being occupied. The relatively small population in northern Illinois and southern Wisconsin is producing a relatively large amount of wheat – 13.9 and 20.2 bushels per capita, as compared with an average for the northern United States of about 6 bushels. The insert shows the westward movement of the center of population, which has not kept pace with the westward movement of the center of wheat production, as shown on the insert to Figure 79.

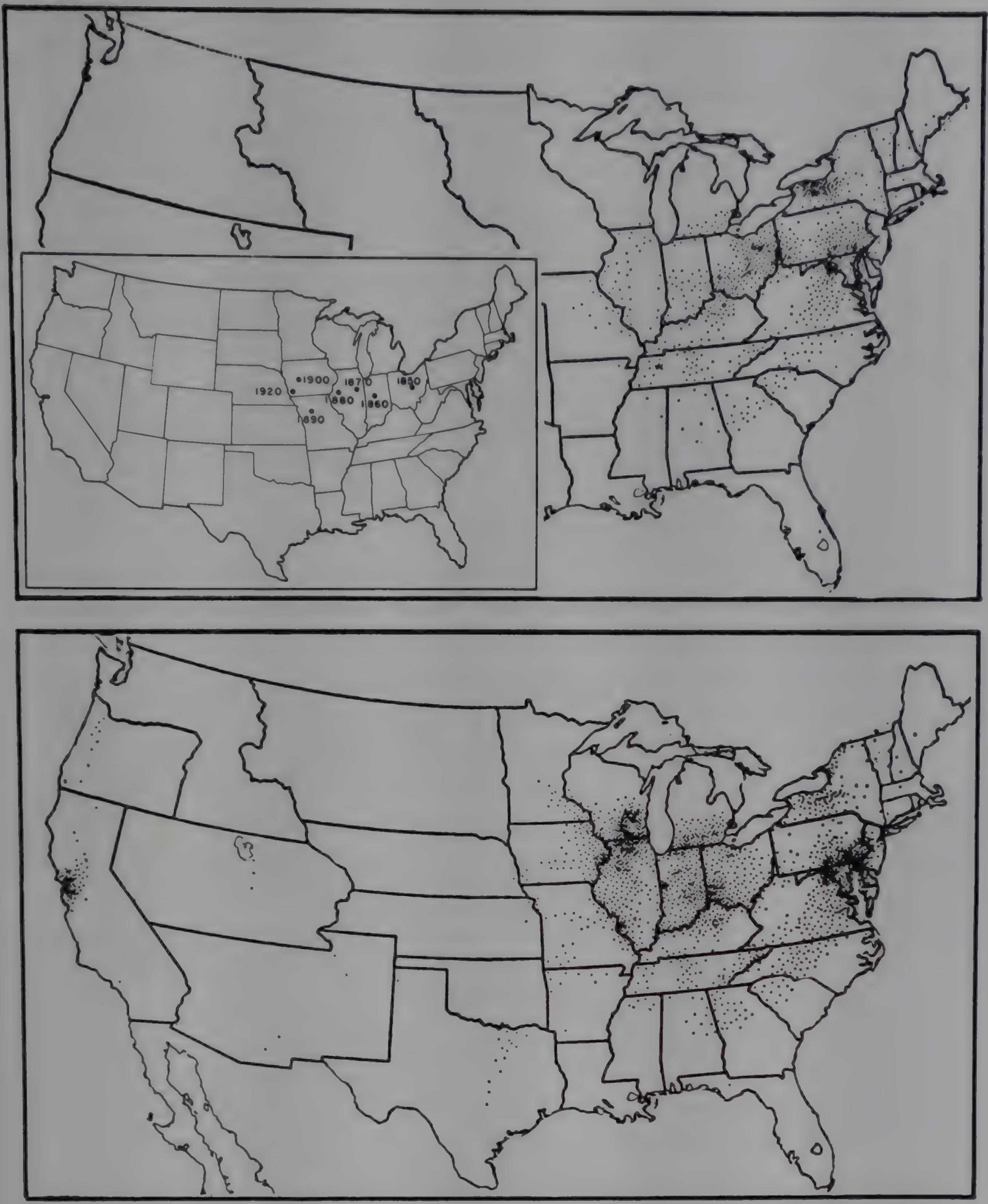


Figure 79. Distribution of wheat-growing in the United States in 1840 (above) and in 1860 (below). Each dot represents 100,000 bushels. In 1840 wheat was grown mainly in eastern Ohio, around Cincinnati, in the limestone valleys of Pennsylvania and Maryland, and in western New York. Ohio was the leading wheat-producing state. Little wheat was grown west of Ohio. In 1860 wheat was still prospering in Pennsylvania and Ohio, but was now also very extensively grown in Illinois (the leading state), Indiana, and Wisconsin. California was by then a considerable producer, and Minnesota was just beginning to grow wheat. The insert shows the center of wheat production for the United States from the year 1850 to 1920.

cent of all American flour in 1840, 57 per cent in 1850, and only 39 per cent in 1860. This decline, it is true, was relative rather than absolute, and due to the faster growth of western centers.

Before 1860 American farmers, millers, bakers, and consumers strongly preferred white, soft winter wheats. In the 40's many farmers shifted to red varieties because of the greater yield, in spite of objections to the darker flour. Winter wheats are planted in the fall and after starting their growth lie dormant over the cold season; in the following year they ripen a little earlier than wheats planted in the spring. Winter wheats suffer from an especially harsh winter, if there is no snow coverage to protect them, but they were more likely to yield a crop in northern latitudes than the hard spring wheats available in 1860. Soft wheats differ from hard in that the starchy endosperm is less flinty and vitreous. Since the flour of soft wheats usually contains less gluten, or gluten of less baking "strength," it does not make as good bread; but with millstones hard wheats had to be given a more severe grinding and the flour was discolored by specks of bran coatings. Because of their better yield and easier grinding, soft winter wheats were preferred for a long time. In 1838, for example, the *Farmer's Register* called spring wheat "the last prevailing humbug," and in 1860 our Census of Agriculture held that "with a better system of cultivation in the West, soft winter wheat will take the place of the hard spring variety."

In actual fact the course of events took a different turn. The most fruitful initial line of advance lay rather in discovering ways to mill hard wheats, with their greater and better supply of proteins, than in improving soft varieties. The changes in milling that brought this about were initiated in this country and abroad well before 1860, although they did not amount to a revolution in milling until the two following decades. After millers found ways to manufacture excellent hard-wheat flour, there was an incentive to search out or create even better hard wheats than had been commonly available, including many of winter as well as spring habit. Soft wheats and other special-purpose wheats were also studied for better adaptation to their special uses. The resulting shifts in wheat-growing areas and the increases in production in this country and throughout the world have had effects which are still being felt not only in agriculture but throughout our economic and social life.

While the Middle West was becoming our grain empire, in the period between Oliver Evans and the eventual development of devices for reducing hard wheats, every phase of American milling was greatly improved except the fundamental operation of grinding. The French multiple-grind system never won adherents in this country; most American millers still used the low-grind system, in which top-grade flour was made by passing the grain but once between millstones set close together, as shown in the typical layout of Figure 80. Here the miller had to follow a hairline between

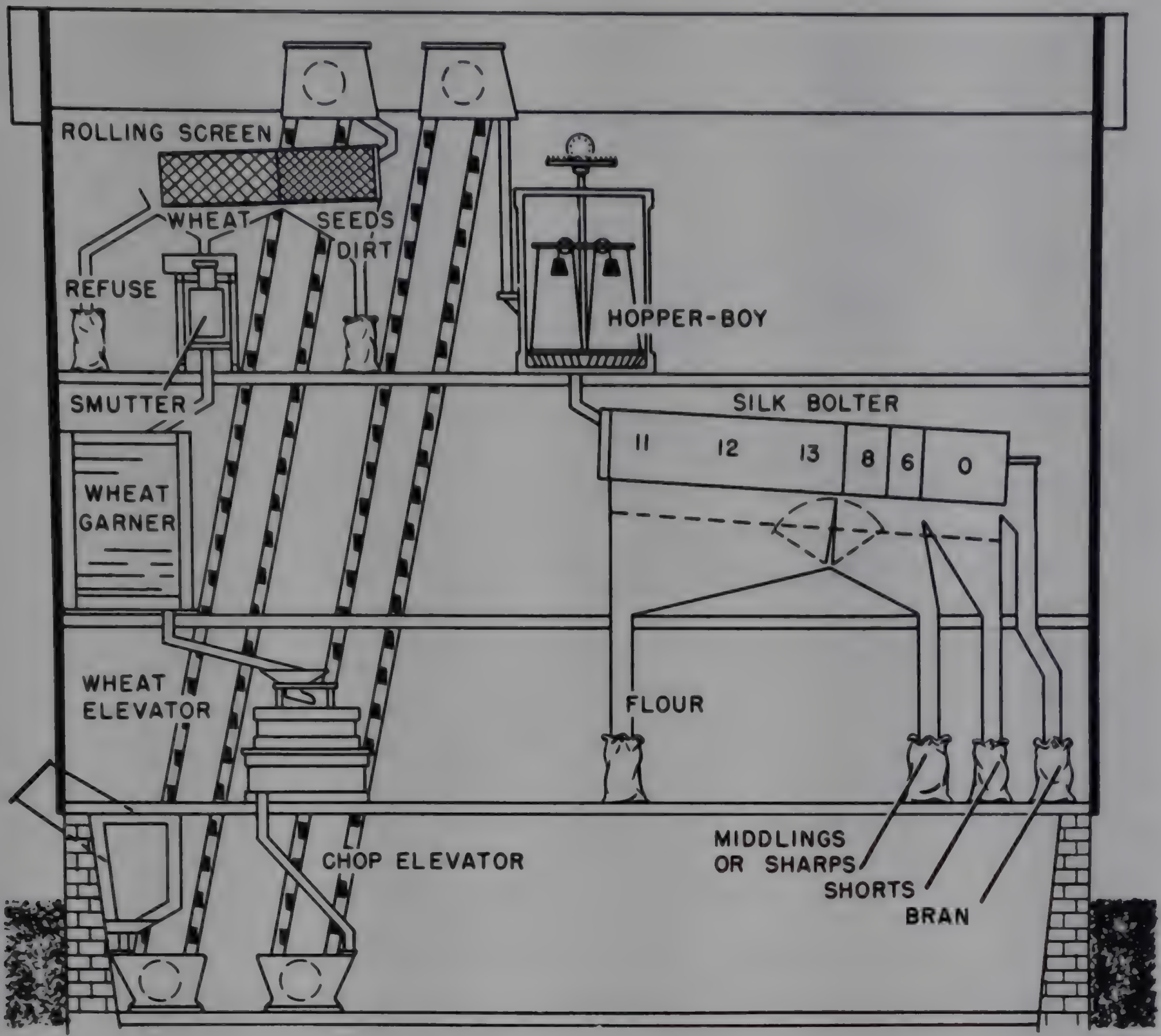

ROLLING SCREEN
WHEAT
SEEDS
DIRT
REFUSE
HOPPER-BOY
SMUTTER
SILK BOLTER
11
12
13
8
6
0
WHEAT GARNER
WHEAT ELEVATOR
FLOUR
CHOP ELEVATOR
MIDDLINGS OR SHARPS
SHORTS
BRAN

Figure 80. Schematic diagram of a characteristic small-size, "Old-Process," automatic American mill of the early nineteenth century. The incoming grain was elevated to pass through a rolling screen and a smutter (Figure 81) for cleaning, and then went by way of a garner to the stones. After a close grinding the hot meal was raised by another elevator for cooling in the hopper-boy, whence it dropped into a slowly rotating silk-lined bolter for separation into the products shown. The numbers on the reel indicate the cloths that were used. An adjustable valve permitted a variable separation between flour and middlings. In mills of this kind the middlings were often reground with the next batch of wheat.

a heavy, steaming meal which would clog his bolting cloths and an overabundance of combined bran and endosperm particles, too large to pass through the cloths. These latter were the exasperating middlings from which only second-grade flour could be made, and low grinding could offer no solution to the problem they presented.

In the preliminary cleaning of wheat, important advances were made. A most significant step forward was taken when it was realized that a number of machines and a variety of processes were needed to do a thorough job. It was in cleaning that air was first extensively employed in

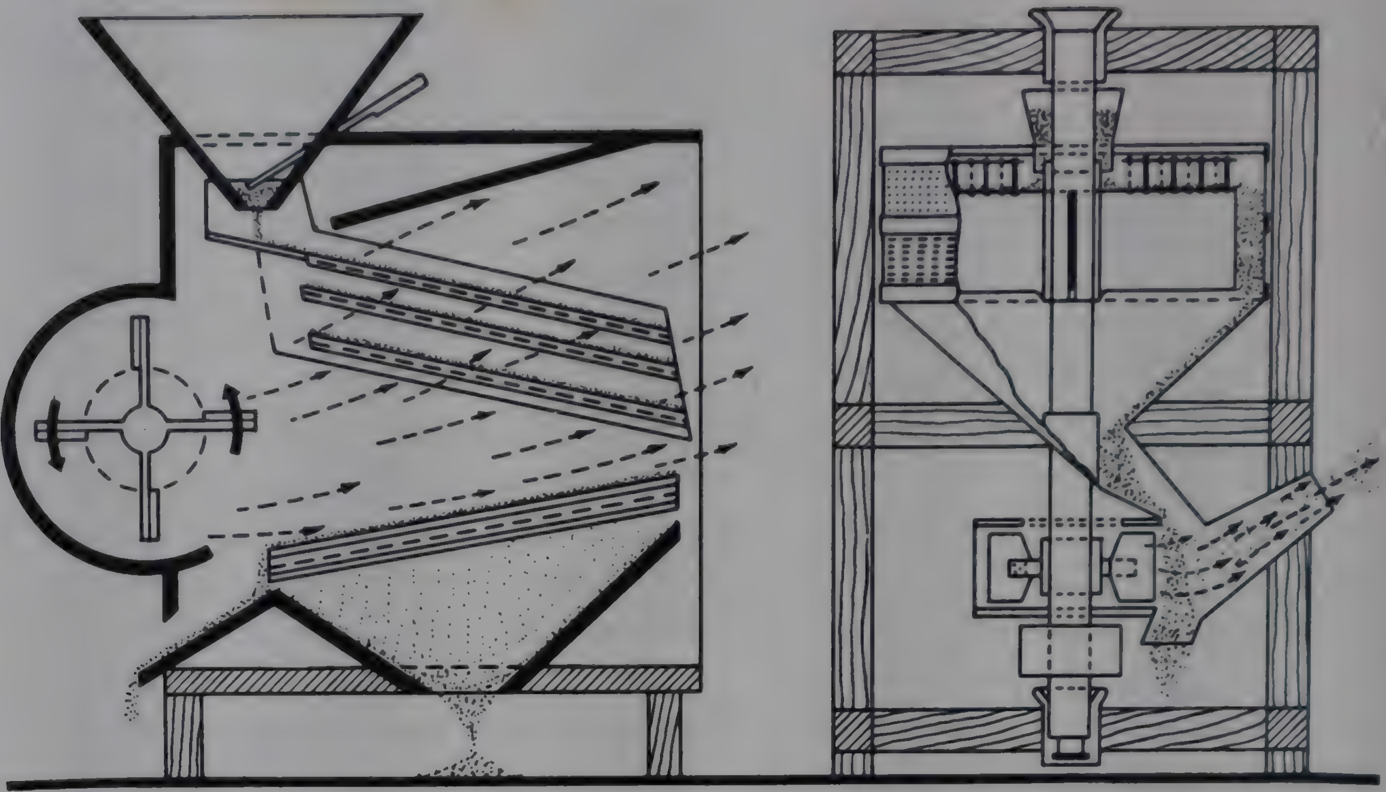


Figure 81. At the left, an early nineteenth-century receiving or milling separator. The upper screens were coarse-meshed, and as they oscillated under mill power, wheat and small matter passed through, while larger matter was tailed over. The lower screen was of finer mesh, and also oscillated, allowing the wheat to tail over, while loose dirt, cockle, and other small matter passed through. A current of air was blown through the upper screens and along the fine lower one to remove easily aspirated particles. This type of machine had been used with a man-turned fan from about 1760 in Germany. At the right, a mid-nineteenth-century smutter, or scourer. The grain entered the machine through the central orifice at the top, and was thrown about within a rapidly rotating perforated case filled with baffle rods, where it might also be aspirated. Loosened dirt and bran was forced through the perforations in the case, while the cleaned wheat dropped down past a fan and was aspirated before leaving the machine.

milling, as blast or as suction; that batteries of sieves were first combined in a single machine; and that centrifugal force was first utilized. The complicated and diverse machines of modern milling made their first definite appearance in this effort to free the wheat berry from dirt and other associated material, to get rid of the beard, to separate sound grain from diseased, and to discover more efficient mechanical methods for attaining these ends.

The rolling screen of perforated metal or woven wire that Evans used for cleaning was cheap and easy to make (Figure 72), but it took up too much space, and only a small part of the cylinder was actually in use at a given moment; consequently it was replaced by horizontal or slightly inclined flat sieves, set one above the other and oscillated by mill power. In many mills two of these machines were used, a "receiving separator" and a "milling separator" which were essentially alike (Figure 81) except that the latter did a more thorough job a little farther on in the cleaning process, with the added assistance of a current of air. This upward current of air forecast the basic principle of the purifier whereby the middlings problem was finally solved, although its possibilities went unrecognized for decades, even after air had been used in a different manner in early makeshift purifiers. Separators of the early nineteenth-century type, although vastly improved and having a gyratory motion to reduce vibration, are still used in the cleaning department of modern mills.

The dust-laden air exhausted from separators and other machines was carried by ducts to a dust room, similar to that shown at 5 in Figure 91, where it was allowed to settle. This dust often contained valuable flour so mixed with dirt and beeswing – filmy bits of outer bran coatings – that it could not be sifted out; sometimes the mixture was so contaminated that it could not even be sold for feed. In addition a spark could set off a fearful dust explosion.

A novel form of cleaning cylinder, called the *trieur* by its French inventors (Vachon, father and son, 1845), made a clever use of centrifugal force to effect a separation between grains of about the same diameter and different lengths – as, for example, between round cockle seeds and elongated wheat grains (Figure 82). The modern disc separator, with its greater

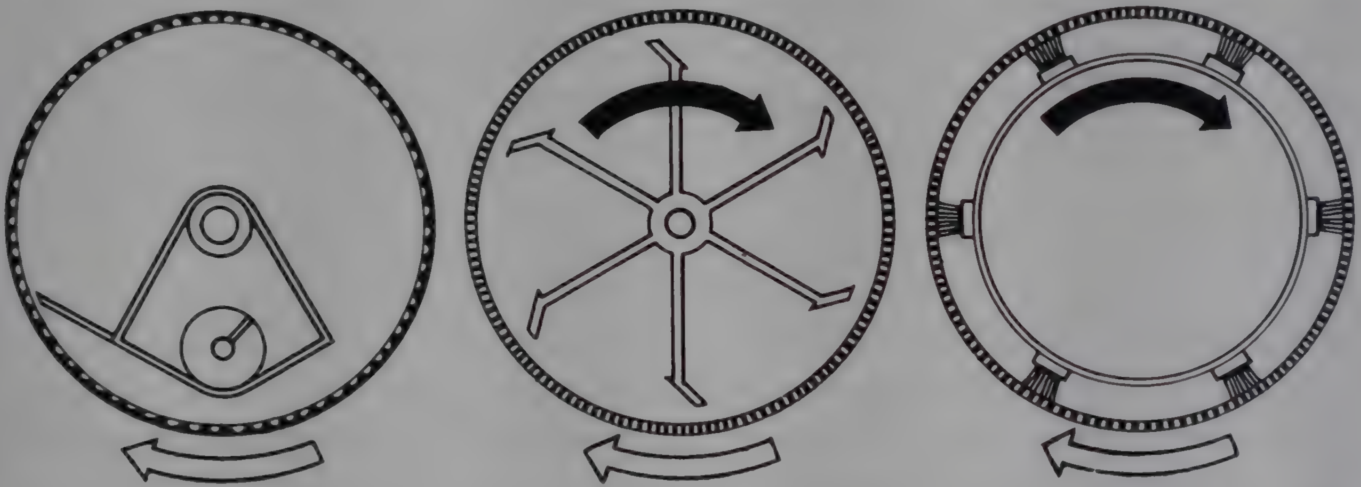


Figure 82. Cross-section diagrams. At the left, a *trieur*, or cockle cylinder. A slightly inclined cylinder whose inner surface was pitted with indentations was rotated at a speed sufficient to carry the materials to be separated above a projecting apron, onto which they were dropped as the cylinder continued to rotate. These materials were then carried out of the machine by a conveyer at the bottom of the apron. The indentations were shaped to accept certain substances and reject others. At the center, a centrifugal reel, in which rapidly revolving beaters inside a slowly rotating cylinder throw the stock against the bolting surface for more rapid action. The beaters were shaped to carry the material being bolted to the tail of the reel. At the right, a bran duster. Rotating brushes rubbed the floury bran against an also rotating bolting surface to scrub off endosperm material. The English force bolters of the early nineteenth century were similarly constructed, although the external cylinder was usually nonrotating.

versatility and more efficient use of the cylinder space, owes much to the cockle cylinder.

A strong dry-scouring action was often rather unwisely used to free the incoming wheat from smut. This was a powdery, ill-smelling fungus infection that became a problem in this country in the late 1830's. It might attack entire grains or get lodged in the crease or beard. Scourers, or smutters, were of varying construction, more or less similar to the machine of Figure 81. The action was severe: some of the outer bran coatings were completely rubbed off and aspirated away, but others were merely loosened to become ground to dust and inextricably mixed with the flour on passing through the millstones. The smut balls were also often broken up and carried on the grain into the flour. Few modern authorities would favor a dry-scouring action, and many are skeptical of the advantage to be gained from the severe rubbing even of dampened wheat — no known technique enables the separation of bran dust from flour when once they have become mixed. The problem of smut is now handled by planting smut-resistant or chemically treated wheats. Where smut is found, the grain is subjected to a very light scouring, sometimes in a smooth cylinder, with high-velocity aspiration to lift the lighter smut balls intact; or the grain is given a special washing treatment.

Mill-powered cylindrical bolters or several-sided (polygonal) reels — the latter an American early nineteenth-century innovation — were commonly used for flour separations. American millers were especially proud of the adjustable divides and double conveyers in their bolters, enabling the distribution of the stock to be altered at will, which had come into common use by the late 1840's. That bolting systems rapidly became bulky can be seen by referring to Figure 91, which shows a mill of the 1860's with complete bolting apparatus. Figure 94 outlines the setup of bolting arrangements in an early nineteenth-century mill as compared with more complicated later mills. In spite of their size the capacity of bolters for an equal cloth area was from one-quarter to one-third that of the flat sifters which later replaced them, especially in this country, except at special points in the mill. In England reels of improved design have continued in general use down to the present day, because of the dampness of the climate and the peculiarities of the wheats milled there. The English were even using force bolters to a slight extent by about 1807 — bolters, that is, with rotating brushes or arms inside the cylinder to push the finer stock through the cloth, not unlike the bran duster of Figure 82.

On the Continent a slanting cloth-lined sifting bag shaken back and forth by mill power was sometimes used for bolting (Figure 83). Such an arrangement would make use of only a small part of the entire cover area of the sifting bag, although the bag might be reset from time to time to bring a new area into service.

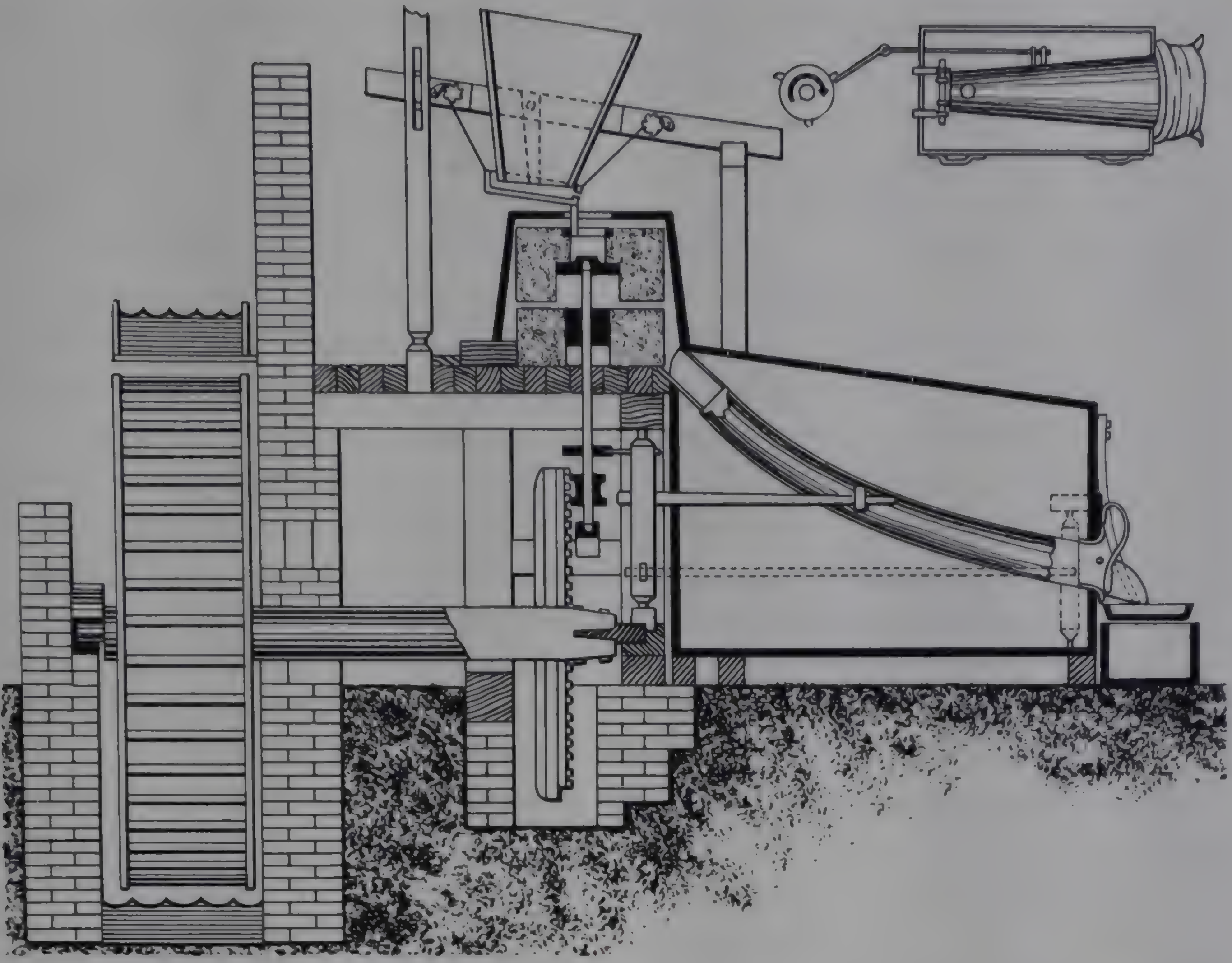


Figure 83. An early nineteenth-century German mill, with long bolting bag shaken by mill power after the manner of the insert at the upper right. A bolter of this type is illustrated in Ramelli (1588). The overs of the bag were given a second sifting on a flat sieve, which was also shaken by mill power.

A packing machine to press the flour into the barrels had been invented by a brother of Oliver Evans, and this or other similar devices came into fairly general use during the first half of the nineteenth century. During this period the flour of American commerce was universally sold in barrels, as was also much bread or ship's biscuit. The "cracker barrel" of the old-time country store has won a permanent place in our folklore. In the late 70's, as American millers began to ship directly to European markets, the advantages of shipping in bags, especially to England, became apparent.

As the nineteenth century wore on, steam was increasingly utilized to turn millstones. Steam had been used in milling as early as 1784 in England, in the famous London Albion Mills, which had been planned by James Watt himself; before that time steam engines ran too irregularly to permit direct application of their power, and from about 1760 had been used sparingly to raise water into millponds. Raising water by steam power was no new thing; Newcomen's steam engines had been pumping water from mines for decades. After Watt's invention of the reciprocating piston, and as the machining of cylinders and pistons permitted the construction of smoother running engines, the objection of uneven action was gradually removed. Still it was felt, in the words of the *Encyclopaedia Britannica* of about 1795, that "the expense of fuel must undoubtedly prevent this mode of corn-grinding from ever becoming popular." As the rich soft-coal deposits beyond the Alleghenies were opened up, even this difficulty was overcome in their vicinity, and numerous mills run by steam rather than by water or wind began to appear. Oliver Evans built a mill powered by one of his own steam engines at Pittsburgh in 1808, and by 1830, when Pittsburgh was already being called the "young Manchester of America," the bituminous coal of Pennsylvania's western counties was burning under the boilers of numerous mills. One of the earliest in this country, it is interesting to note, was operating at that date in central Illinois, also a region where coal was more plentiful than water power.

Because flour milling was already well established at the best water-power sites, it changed over to steam power more slowly than other industries, especially such newer industries as iron and steel milling, which required large amounts of power and underwent an enormous expansion in the nineteenth century. Power statistics are lacking from censuses prior to 1870, but by that time, so far as American industry as a whole was concerned, steam engines had just managed to pass the horsepower output of water wheels (including turbines); in flour and grist milling of all kinds, however, steam engines still produced only two-fifths as much power as water wheels.

Steam power of course allowed much greater freedom in the location of mills. In 1880, when one and one-half times as much water power as steam power was still being used in milling as a whole, the ratio had already been decisively reversed in certain parts of the country where the terrain was flat. Thus in Illinois and Missouri almost four times as much steam power as water power was being used and in Indiana the ratio ran two to one, while Minnesota, New York, and Pennsylvania – very important milling states with substantial water-power resources – together were obtaining over three quarters of their milling power from water wheels.

By 1890 steam power in milling had drawn alongside of water power, and by 1900 it was one and two-thirds times as great – a ratio which has been maintained, approximately, to the present. But at the turn of the century electricity began to figure modestly in milling, following the first all-electric flour mill set up in 1887 at Laramie, Wyoming. By 1920, in merchant milling as in industry as a whole, electricity supplied almost as much power as steam, and by 1940, when all industrial uses of electricity exceeded uses of steam by two and one-half times, in milling the ratio of electricity to steam was four to one. A substantial part of this electric current, of course, is derived from great hydro-generating plants, such as that

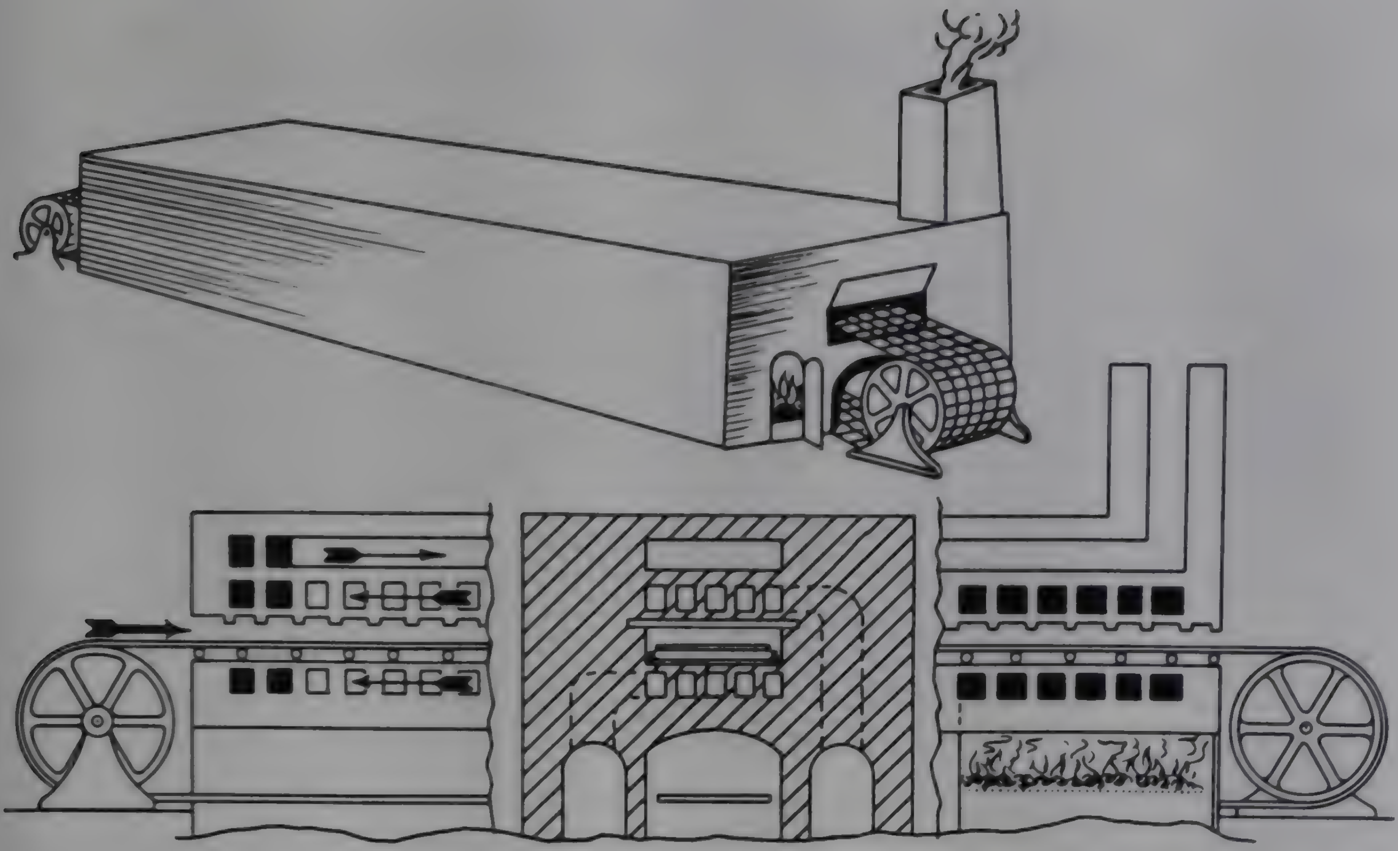
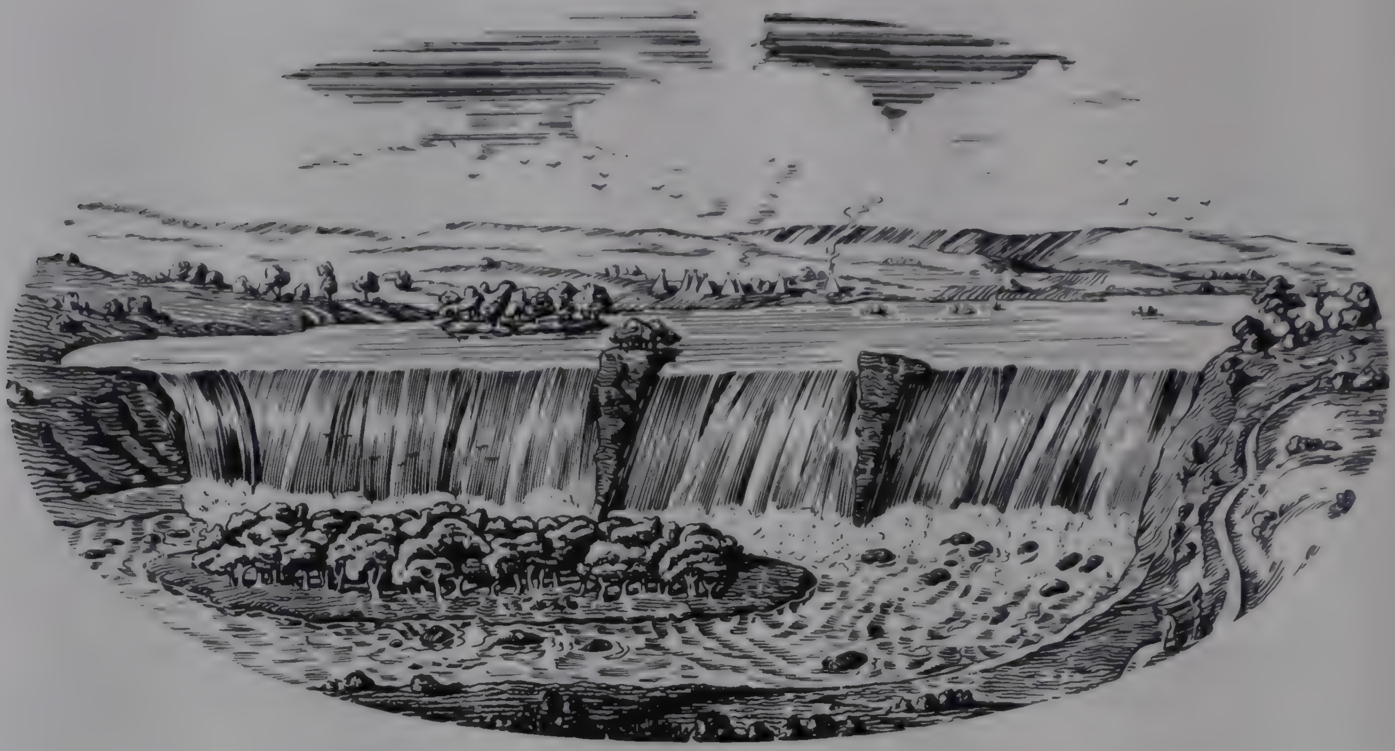


Figure 84. Coffin's "perpetual oven," developed in 1810 for use by the British Navy. The inner cross section below shows the system of flues above and below the baking area. The loaves enter the oven on an endless belt at the end opposite the fire and are slowly brought to the area of maximum heat.

at Niagara Falls, which supplies power to Buffalo and much of upper New York State. These mammoth turbine-operated generators are most impressive descendants, in the direct line, of the primitive water mill Vitruvius first described two thousand years ago.

Paralleling the nineteenth-century advances in milling, the associated art of baking was also becoming mechanized. In 1810 Vice-Admiral Isaac Coffin had invented "a perpetual oven for baking all kinds of bread" in order to satisfy the needs of the British Navy (Figure 84). It will be noted that the belt of Coffin's oven ran outside the baking chamber at either end, the result being a substantial heat loss – a condition which was not remedied until the 1850's. Thus began a line of progress which has led to the mechanized bakeries of today, where dough is kneaded and the loaves formed, baked, cooled, and wrapped without being touched by anyone's hands.

The impetus given in this country by Oliver Evans and in Europe by the revival of the French Process carried milling, along the lines of advance we have been summarizing, to the point at which two great and fundamental inventions, the purifier and the chilled-iron roller for grinding, would complete its modernization. These inventions, more than any other, are responsible for the present character and immense achievements of the art of grain reduction, and their story deserves separate consideration.



CHAPTER XIV

Automatic Milling and the Purifier Start a Revolution in American Milling

> In the sixties and seventies the best principles of French and Hungarian milling were Americanized and reconstructed on the Yankee plan of an automatic mill.
>
> —George D. Rogers

In the United States during the decades after 1860 flour milling completely altered its character. It became a thoroughly mechanized, large-scale industry, drawing its ever more varied wheats from ever more distant sources, submitting them to a cleaning and reduction program whose broad outlines were thoroughly standardized, producing flours and feeds of remarkable purity and uniformity, and disposing of a constantly increasing volume of production in ever expanding markets.

During this period engineering became the mistress rather than the handmaiden of invention, but the achievement of these decades in milling went far beyond the invention and sound engineering of new machines. It lay in the synthesis of a magnificent and totally new system of milling whereby the wheats of the world—many of them new types bred by man

Chapter head oval. The Falls of St. Anthony, at the present site of Minneapolis, as sketched by Jonathan Carver in November 1766.

and grown under conditions of climate and soil previously alien to the plant — began to yield the foodstuffs essential to modern urbanized democratic life, in quantity and quality alike. The flours and feeds of industrialized milling are new syntheses, only generically similar to the products of earlier milling. They satisfy only part of our food requirements, whether we consume them directly, or indirectly in the form of meat; but as an abundant and cheap energy food they supply the foundation of a diversified diet for our multitudes. The products of contemporary milling are among the essential bulwarks of modern democracy.

Throughout the whole course of our story millers have been struggling with the problems of separating the small but complex wheat berry into its principal elements — the central floury endosperm so easily assimilated by man, the bran coats whose cellulose is too harsh for human beings but which animals can digest, and the germ by which life is transmitted to the next generation of the plant. The nineteenth century saw the beginning of a scientific attack on these problems, in a study which has not scored a complete success, even yet. Although wheat berries on the average contain about 85 per cent endosperm, 13 per cent bran, and 2 per cent germ, in normal times even the millers of today seldom plan for more than a 72–75 per cent extraction of flour: their remarkable methods and machinery still fail to recover about one seventh of the endosperm, and will include about the same proportion of the bran and germ in the flour. Here is an indication that the story of milling has not yet ended, even in these advanced processes that have gone so far beyond the achievements of the old rule-of-thumb miller.

It is time to look at this stubborn wheat berry as modern science has dissected it for us (Figure 85). It is a small, nutlike seed scarcely more than a quarter of an inch long, with a troublesome beard at one end. A handful of wheat picked up at random will be far from uniform in any dimension, so that grains will respond variably to almost any cleaning or reduction process. The starchy core is closely covered by a number of fibrous coats, of which the three outer layers, or pericarp, corresponding to the shell of a nut, are the more brittle, especially in hard wheats, while the inner layers, or seed coat proper, adhere tightly to each other and to the endosperm. To this they are joined by the larger, heavy-walled, cubical aleurone cells, which contain a considerable amount of protein, and if broken sap the baking strength of the flour. The harsh outer bran coats are easily shattered during grinding, when finely broken up cannot be separated from the flour by any known method, and if present will affect its color and baking quality. Then there is the seed proper, or germ, which strongly resists granulation, but under pressure acts somewhat like a soft metal and will disintegrate if rubbed too thin. A vitamin-rich oil can be pressed from the germ, but in flour this oil has an unfavorable effect on color, baking quality, and keepability. The starch cells of the nutritious endosperm itself are easily broken in grinding, starting chemical reactions which weaken the flour. Again, flour can be seriously injured by excessive pressure or heat during processing.

To complicate matters, the berry is deeply folded in on itself along its entire length. At the bottom of this crease are the cells of the dried-up pollen tube—the so-called crease dirt which was given an exaggerated emphasis in the early days of the milling revolution. These cells are especially dark, and if not removed from their almost inaccessible retreat can

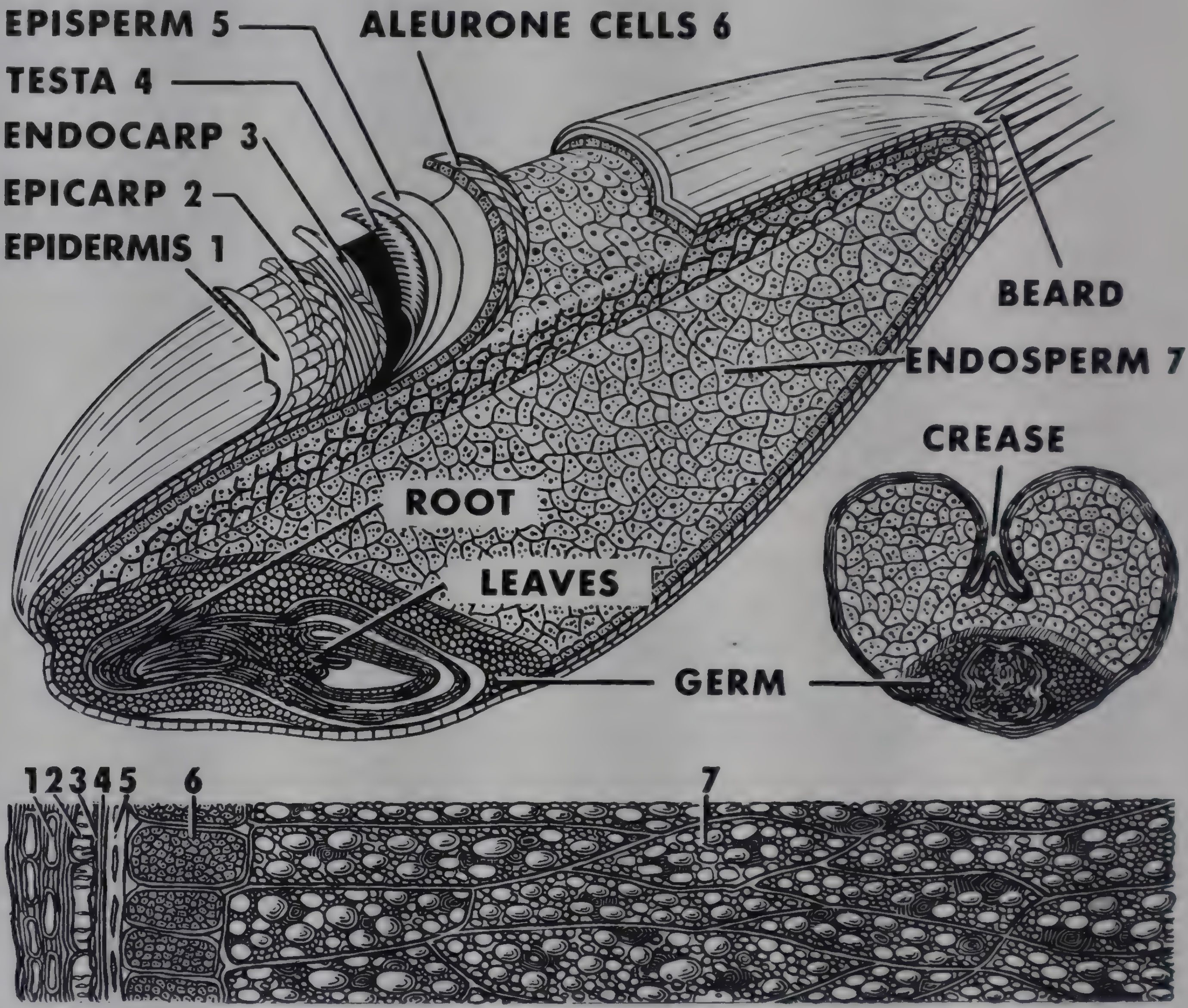


Figure 85. A grain of wheat. Above at the left, enlarged 20 times in length, with a wedge amounting to about one quarter of the grain cut away. At the right, a cross section through the lower end of the kernel, with the crease somewhat spread apart to show its structure. Below, a section enlarged 280 times to show the starch granules in the endosperm cells. Layers 1–3 of the berry together form the pericarp; the inner layers, the seed coat proper, with the testa giving the grain its characteristic color. In addition to starch cells, the endosperm contains the gluten required to hold the carbon dioxide released by fermentation of the yeast added to the dough in breadmaking. In modern milling the coats and the germ go mainly into animal feeds, their high protein and vitamin content thus being rendered indirectly available to man.

contaminate the flour. So will dirt or any other foreign matter which has lodged in the crease.

Finally, different varieties of wheat are quite unlike in their characteristics, the same wheats will vary considerably from season to season and from district to district, and bulk grain comes to the mill mixed with all manner of alien substances – tiny sticks and stones, wire and mud and dust, other seeds and spores, excess moisture, parasitic infestations, and a thousand unsuspected surprises. As little as 0.2 per cent of fine outside dirt can discolor a straight flour. If badly stored, wheats go through a change known as sweating. In a modern mill, the storage of wheats, their cleaning and preparation for grinding, and their reduction demand constant vigilance and an instant resourcefulness. This list of difficulties should give us a keener appreciation of the product of modern milling.

It is not surprising that the wheat berry was quite literally a hard nut to crack, even with the best and most skillfully operated millstones. Until far into the nineteenth century even the most advanced millers had to make a Hobson's choice between quantity and quality of product – between getting something like a 75 per cent extraction composed mainly of a single fairly satisfactory flour plus a small amount of low-grade product, or considerably less of a somewhat better flour along with an almost equal quantity of low-grade. In either case the miller ended up with about 25 per cent of by-products.

American and English millers on the whole worked for quantity: their wheat was often hastily cleaned and then ground once, fast and low – with the stones set close together. As we have seen, the middlings made in grinding were often thrown back for regrinding with the next batch of wheat, a sure way to downgrade the product. Similarly, once-bolted materials were frequently returned to the same reel for rebolting, mainly to keep the bolt sufficiently supplied with stock. It was the proudest boast of the American miller that he could make a barrel of flour out of less than "4 30/60" bushels of wheat – which works out to a little under 75 per cent extraction when the wheat weighs 60 pounds to the bushel and a barrel holds 196 pounds of flour.

Some of the French millers – by no means all – were almost alone around 1800 in striving for quality in their product. These advocates of the *mouture économique* cleaned their wheat more thoroughly than was the custom elsewhere, and then ground high, slow, and repeatedly, usually on smaller stones than were common elsewhere, and always with a careful hand-bolting after each passage through the stones. They developed crude devices for treating the greater quantity of middlings made by their method of grinding, and produced several grades of flour, of which the best was distinctly superior to most English or American flours.

It must not be thought, however, that either method yielded anything equal to a modern flour in quality. The varieties of wheat grown a hundred years ago are no longer raised and could not compare with the hard wheats of today as sources of bread flours, but our milling processes would give us a better product even if they were applied to the soft wheats formerly grown. In an experiment with a modern soft English wheat, a type probably not greatly different from soft wheats of former days, bread was made from flour ground by millstones and by modern rollers. The millstone bread scored 35 on a point system and the roller bread 58. With English Fife, a rather harder wheat, the millstone bread scored only 25 and the roller bread 80. The millstones made better flour from soft wheat, the rollers from hard, but in both cases roller flour was superior to stone-ground. If this test had included the numerous grindings and boltings of the *mouture économique* in its stone grinding, the product would undoubtedly have been improved, but hardly to the point of matching even the roller flour made from soft wheat.

The contrasting systems of milling for quantity or for quality were typical of societies with equally contrasting social structures, and each was carried to an extreme in a part of the world where the contrast was especially pronounced. The single straight flour of England and especially America crudely symbolized a single food standard for all, which of course was far from actual realization at that time anywhere, but was most nearly approached in those countries. The French quality system of milling was predicated on a division in the social order so deep that it extended even to life necessities. Inferior flours constituted approximately 50 per cent of French production, and were consumed by the common man; but a superior flour was available for those who could afford it and had cultivated a taste for finer things. Both groups of consumers were needed to support the French quality miller. In England and America there would certainly have been an indifferent market for the poorer French flours, but it is also true that few would have been able to pay the considerably higher price of the best. Bread was simultaneously dearer and cheaper in France than in England and America, better and worse in quality. When American mills would improve their standards of quality, the product would be available to all.

An eighteenth-century French quality mill required more workers per unit of product than typical American or English mills, since even the bolting was done by manual labor. But if we had traveled eastward into the highly feudal Austrian Empire only a little later, we should have found the contrast still greater. In the number and variety of processes and machines, and above all in amount of hand labor, the Austrian and Hungarian mills from about 1825 went so far beyond even the French as to get their system called *mouture en infini*—milling to infinity. In one account of this East European system of gradual reduction, mention is made of 84 classes of partial product – middlings and the like – each requiring individual handling from machine to machine for a long time with but little benefit of conveyer, elevator, or spout. Hundreds of little buckets stood around the mill, each in position to receive its own particular material; scores of men busied themselves carrying the products in the buckets on to the next stage of processing, on the basis of decisions made on each batch of stock by the head miller. To an uninitiated observer a mill of this kind must have seemed as mysteriously confused as a busy ant hill, but actually an all pervading system controlled the curious activity, and each operation was definitely related to the others in a sequential chain. Alter any one process, and you would have to change many others to get a satisfactory result; let something slip ever so slightly anywhere and not one but possibly all of the ten or so grades of flour and several varieties of bran might be injured.

This Hungarian milling system originated in days when machines were so imperfect that they needed constant surveillance. It could be profitable only in a highly stratified society that could guarantee a market for the 10 per cent or less extraction of extremely white *Kaiserauszug* (Emperor Extract) flour, for the 40 per cent of wretched black flours, and for all the grades in between; a society possessing a small but very demanding aristocracy, much cheap labor, and little incentive to improve its limited mechanical aids. Also, the system was adapted only to a hard wheat that required gradual reduction and could stand the treatment to which it would be subjected by very imperfect machinery. For some decades the milling of the central Danube Valley was geared to these very special conditions. By the 60's Hungarian milling had gained an awesome reputation for the complexity of its processes and the quality of its best products, but its methods were completely impractical outside their place of origin. When certain American millers in our Northwest a little later tried to adopt the system wholesale by importing Hungarian machines and Hungarian head millers, the result was lamentable.

Yet the basic philosophy of Hungarian gradual reduction was important and viable elsewhere: it revealed the most fruitful line of advance for modern milling by concentrating on the previously neglected middlings as the very basis of a successful gradual-reduction process. Still more important, practically every sound line of mechanical advance in milling for decades was first indicated either by the Hungarians or the French, in machines which often were little more than rough sketches of what later engineers would devise. These influences were valuable to the West, even though the French particularly resisted rather than aided the introduction of refinements in milling methods. As late as 1885 the French Ministry of War still required flour for the army to be millstone ground.

Hungarian wheats began to be more than locally known near the end of the eighteenth century, when we first hear of *Wiener Gries* – Vienna grits – made from the hard winter wheats of the Danube Valley, being sold in places as far distant as Paris, Berlin, and Hamburg. These wheats were too flinty, and were encased in a bran too brittle, to permit of ordinary low grinding; but it was found that they could be cracked by stones set far apart with the runner stone firmly held on a stiff rynd. The grist was placed in tubs and shaken until the bran rose to the top, to be removed with small shovels. After grading for size through hand sieves, the meal was ready for sale. During the sifting it was found advisable to stand near an open door or window, so that the draft might blow away any loose bran, after the manner in which wheat had been winnowed in the open for thousands of years. Some even used a hand bellows or fan under the sieve to assist the separation.

We have here a primitive use of air to "purify" or effect a separation between the bran and other particles of a ground stock. Air had previously been used not only to winnow wheat in the open, but to clean it in the mill. We recall that Evans in 1795, for example, ran an air blast through stock from the rolling screen, through a receiving hopper and the ending stones that cleaned the grain somewhat without breaking it, and even into elevators and conveyers (Figure 72). American millers were also early using an air exhaust on millstones to cool the chop and prevent moisture condensation, and cleaning separators were served by air blasts (Figure 81). Though none of these uses were sufficiently under control for the extremely delicate purposes of a well-developed purifier, they were certainly as well conceived as the earliest versions of air purifying.

When Ignaz Paur of Leobersdorf tried the experiment of regrinding the grits with stones placed closer together, to make what he called *Auszug*, extract flour, the demand for his product was so great that in 1807 he invented the first middlings-purifying machine definitely known to us (Figure 86). Rollet in his *Mémoire sur la meunurie* (1847) mentions a French "middlings ventilating machine analogous to that used for cleaning wheat" which is credited to Pinet from about 1775, but he was unable to find a drawing or further description. Paur later improved his purifier somewhat by bringing the fan closer to the point of action, by adding a vibrating sieve outside the range of the air current to grade the material going to each section of the purifier, and by providing an automatic elevator to raise the ground stock onto the sieve. The idea of grading the stock before submitting it to the air current was a basic innovation, since good air separations are impossible unless the particles acted upon are of very nearly the same size.

Thanks to Paur's methods, millers from about 1814 found a good market for the extremely hard Banat wheat. Though his machines were so defective that the stock had to be run through them several times, for want

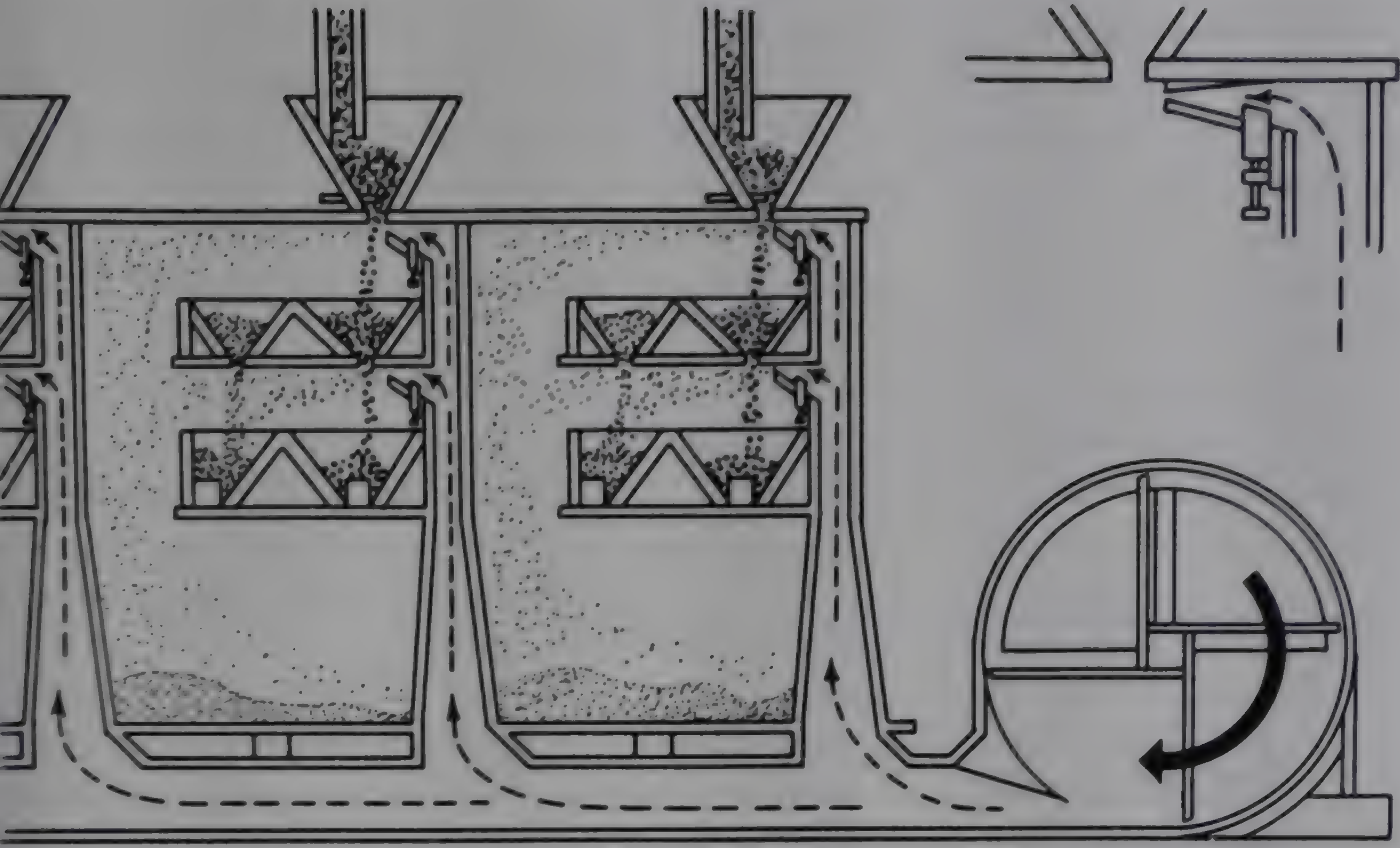


Figure 86. The first purifier, invented by Paur, an Austrian miller, in 1807. The stock was dropped from a number of hoppers in line, across a blast of air which divided it into grades. At the upper right, the adjustment for regulating the blast.

of something better they were eventually installed in most of the larger mills of central Europe, including Hungary. They were also in use in 1847 at St. Denis in a mill run by P. Benoît, a progressive miller who had translated Oliver Evans into French; but Rollet notes that the stock from his machines had to be given a hand sifting. Material entering Paur's machines was not graded carefully enough, in spite of the sieve on his later model, and the fans were not subject to sufficiently delicate control, in spite of the adjustable orifices and flaps in the air chamber to guide the blast. We see here an instance of the need for better engineering design than would be available for some decades: ideas were plentiful but they could not be realized completely because technological skills were undeveloped.

However, with Paur's device perhaps the greatest difficulty lay elsewhere: his air blast filled the mill with flour dust, since no one knew how to make a suction fan work successfully in a dust stream. The coughing millers must often have wondered whether they were benefited by the new invention — and in one unsuspected way they certainly were not. Paur's purifier tended to increase the size of the mills, and as they grew, mysterious fires and explosions became more frequent. For decades no one saw a connection between these disasters and the increase of dust in the mill; it was not realized that fine dusts of any description are highly explosive. It was not until 1867 that the discomforts created by Paur's useful but troublesome device were somewhat relieved, when J. Woerner partially solved the problem of drawing the dust into settling chambers by means of suction fans. Woerner's purifier and other machines with exhaust fans, however, rather concentrated than eliminated the dust and its dangers. Without good dust collectors they were a qualified success.

These early machines were gravity purifiers; an air current effected separations by acting at a right angle to the moving stock, across its direction of fall. Charles Haggenmacher, a noted Budapest miller and inventor, devised a deceptively simple gravity purifier in which the same action was applied a number of times over (Figure 87). This aspirator became very popular in Austria and Hungary, where it was well adapted to the larger

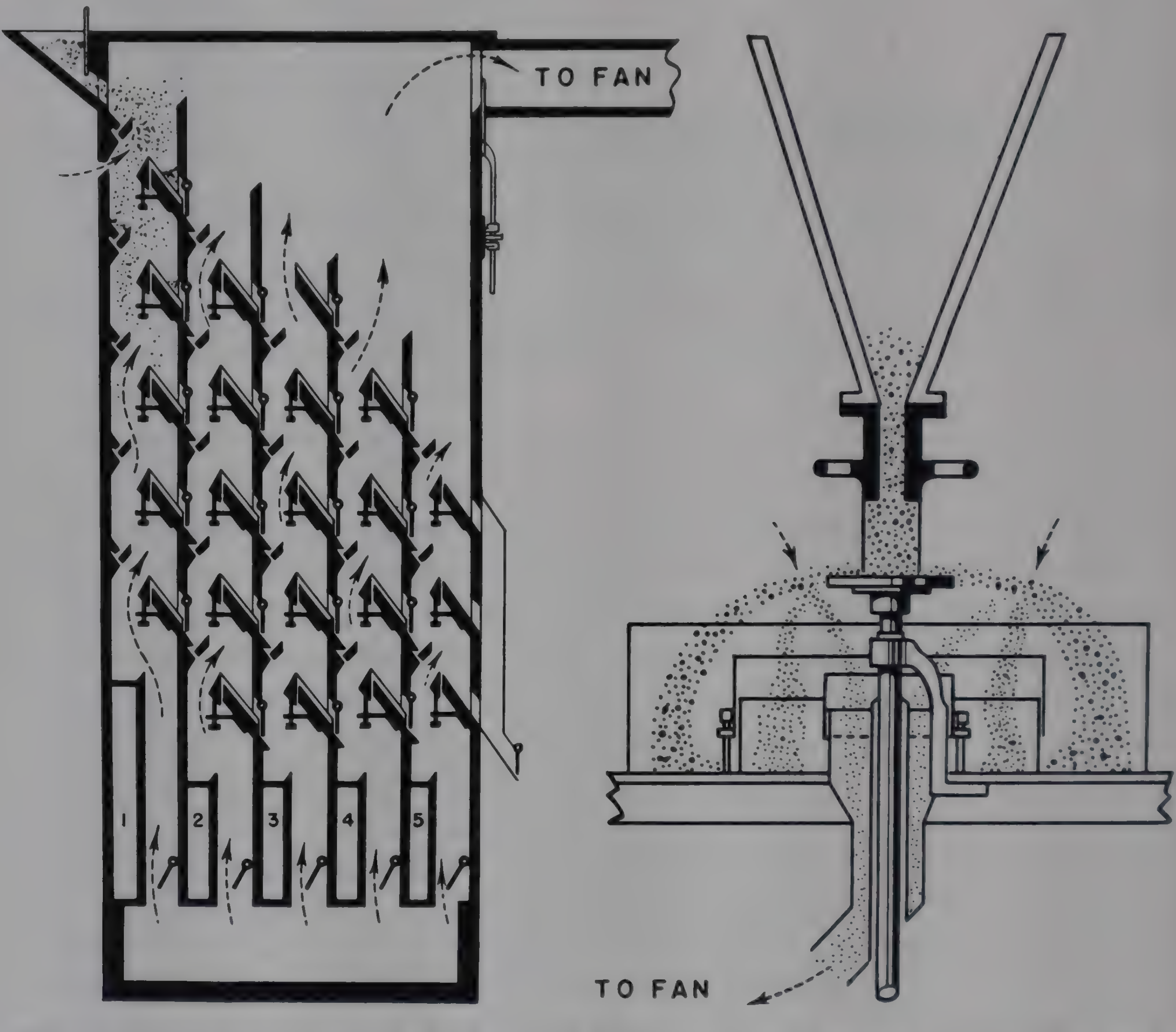


Figure 87. At the left, one of the forms of Haggenmacher's gravity purifier. The stock passed down and diagonally through a rectangular trunk fitted with adjustable baffle boards, and was crossed by air currents. The heaviest middlings resisted the air currents most and fell into receptacle 1, while each succeeding receptacle received lighter particles. Although this particular machine was intended to yield five varieties of middlings, it was successful only on heavier stocks. At the right, Buchholz's centrifugal purifier. The stock dropped onto a rotating plate and was thrown out into an air current. The heavier particles fell into the outer receptacle, while the dust was drawn into the central passage and carried to the fan.

middlings ("sizings" or "semolinas") there produced. It did not work so well on the smaller middlings characteristic of American, French, and English milling, or on ungraded stocks. But the basic idea of this machine was easily adapted to wheat-cleaning, especially where fine dusts must be separated from the grain.

Rollet in 1847 described a French machine "of great antiquity," the *lanturelu*, or "fiddlestick machine," in which centrifugal force and air currents were crudely employed to separate bran from middlings. The action must have been hit-or-miss, yet the use of centrifugal force was a commendable innovation. In 1876 Buchholz patented a centrifugal purifier of good design, its only weakness being insufficient capacity (Figure 87). In the spate of American milling inventions of the 70's, centrifugal purifiers appeared on the market, but failed to win favor; the most promising immediate line of advance lay neither in this direction nor in that of the gravity purifier but in a combination of aspiration with sieving. In 1941, however, the Hart-Carter people offered a Purograder in which centrifugal force was once more used, but under modern controlled conditions, to separate purifier stocks.

Even before any significant attempt had been made in the United States to use a purifier, certain millers in the Cannon River valley of southeastern Minnesota, about fifty miles south of Minneapolis, had become famous for their success in milling the hard spring wheat of the Northwest. This wheat had come originally from Galicia in the southern part of what was then Poland, on the northern borders of the hard winter wheat region of the Danube Valley. It differed from the most used Danubian wheats chiefly in its spring habit; like them it had a hard gluten-rich endosperm and a brittle, easily shattered bran. It had been brought from Galicia to Germany, and thence to Scotland; a Scotch settler named Fife, living in Canada, had received and planted some successfully, and after him it got its American name; finally from Ontario it reached the Northwest. There, as in its original home, it was grown in regions where the severe continental climate would destroy fall-sown wheats.

Like their wheat, some of the Cannon River millers had come from Canada, including the well-known brothers John S. and George N. Archibald and one man, Alexander Faribault, who was the son of a French fur trader. These men set up mills at Dundas and Faribault in 1857, having been preceded the year before by North and Collett's mill at Northfield; and within a few years fifteen flour mills were in active operation along a twenty-mile stretch of the river. Probably led by Faribault, some of these millers — Faribault, the Archibalds, Gardner at Hastings, Mowbray at Winona, and perhaps others — were soon using the French quality milling process in a slightly modified form to meet American conditions. George D. Rogers, who as a boy himself saw the famous Gardner mill at Hastings, Minnesota, thus described the process:"By reducing the pressure and increasing the number of grindings, the Hastings mill avoided the undue heat which injured both the color and quality of the flour; and by special pains with both stone-dressing and bolting, the Gardner mill turned out a product which sold in the east at one to two dollars per barrel higher."

The manner in which the stones were dressed probably differed considerably from French practice; American millers had always devoted much attention to their millstones, and even low-grind millers were accustomed to leave less land – less ungrooved space – on their stones than usual elsewhere. Hand bolting was seldom practiced in American mills, and the reels were almost always hexagonal or octagonal, rather than circular as in many French mills. The reels were probably clothed with more varied meshes than were used by the French, enabling a greater number of separations by a single bolting. Grades of flour made were as few as possible, in view of the American market – a change that was simple because of the ease with which hard wheat responded to high grinding.

The success of this improved process had profound effects. Whereas Minnesota's entire production of wheat had been 1,401 bushels in 1850, with flour production valued at $500, in 1860 the state had eighty-one mills and 2,187,000 bushels of wheat were grown. In 1859, for the first time, the wheat shipped from the state was more valuable than the furs, and at about the same time the demand of the mills for grain became so great that considerable quantities were imported up the Mississippi from Iowa. In 1859 a visitor in Hastings reported: "There was wheat everywhere; wheat on the levee; wagon loads of wheat pouring down to the levee; wheat in the streets; wheat in the sidewalks; warehouses of wheat; and, verily, wheat was the one idea of Hastings the afternoon we arrived there."

In 1860 the river trade of Winona, Hastings, and Red Wing amounted to 1,950,000 bushels. In that same year a little more than half of Minnesota's tilled area was in wheat. For some time the difficulties were enormous. Until a connection by rail with Milwaukee was established in 1867, almost all of Minnesota's exports went down the river to St. Louis, in spite of the fact that, according to a state legislative report of 1861, the mean distance of a Minnesota farmer from a navigable river was eighty miles, requiring a six-day journey there and back for a thirty-bushel wagon load. In spite of these difficulties, from 1862 to 1867 Red Wing was the world's principal primary wheat market.

In 1865 Faribault induced Nicholas and Edmund N. La Croix to come from Montreal to build a mill for him. The La Croixs were quite possibly not the first in the United States to use air to separate bran from middlings; Stephen Gardner in his Vermillion Mill at Hastings may have used an air blast on ungraded reel tailings almost simultaneously with the La Croixs'

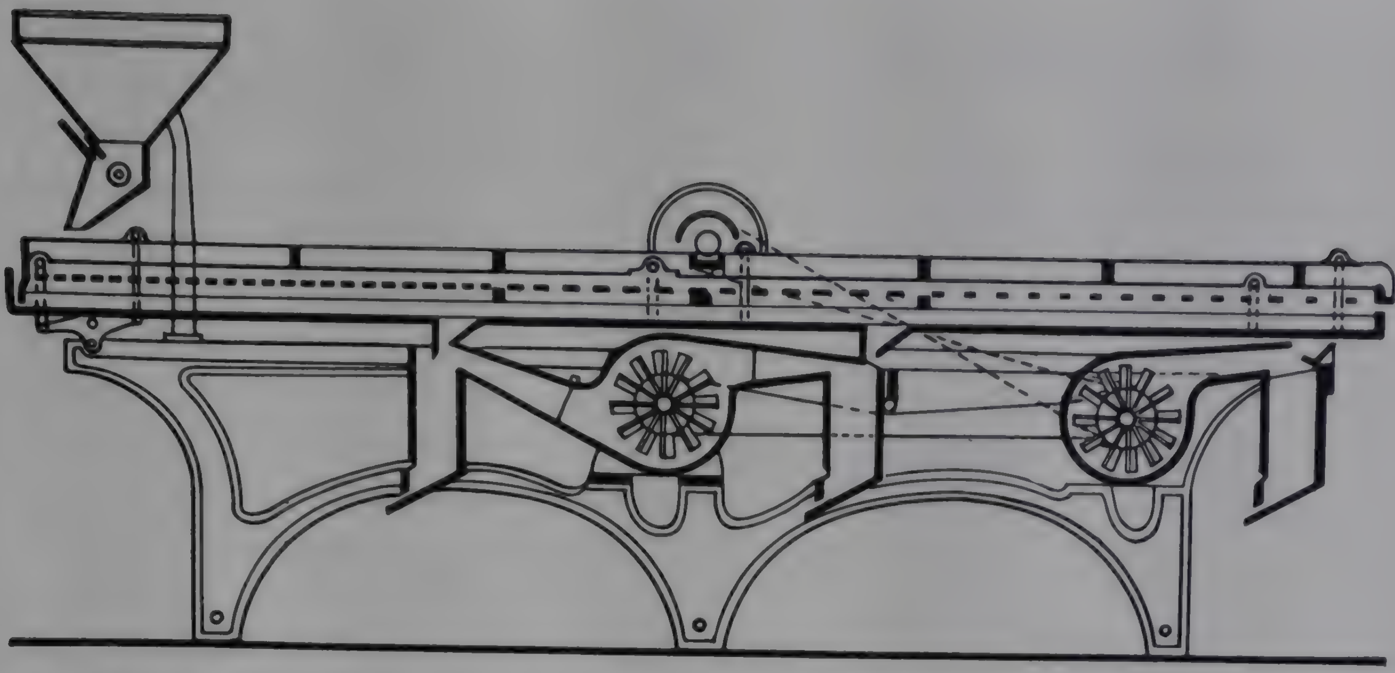


Figure 88. Cabanes' mechanical sieve, patented in 1855, in which air from two fans under an agitated sieve and one above it was used to hold light materials in suspension while three separations were being effected. The bran passed over the tail of the sieve, while the three grades of middlings dropped through it into receptacles, being subjected to an additional aspiration as they fell. Cabanes may have originated the extremely important idea of assisting separations by sending air through a sieve.

arrival at Faribault, and a process patented in 1865 by John Brown had been used for middlings-cleaning in mills from Buffalo to Providence by this date or earlier, the flour being marketed under the name of "Patent Haxall" after the famous Richmond mill. But the La Croixs were the first to introduce machines which made continuous improvement possible by arrangements for grading the middlings as well as for subjecting them to an air current. Even in this respect Benjamin Barter's flour dresser, using air, was a close approximation; but the approach of the La Croixs was more fundamental, and had the advantage that it was made in a region having a hard wheat in need of purification before it could compete with wheats already on the market.

The La Croixs were skilled, French-trained engineers, familiar with the theory of the purifier as it had been discussed in France before their departure for Canada. They also had some acquaintance with at least one actual machine – that of Perrigault, which had been patented in 1860 – and probably with Paur's purifier. They may also have known Cabanes' mechanical sieve (Figure 88), which had been patented in 1855. Perrigault's machine was far more complete than Cabanes'. On a visit to Trieste he had noticed that the women and children engaged in hand sieving were taught a certain combination of motions that had the effect of bringing the lighter materials quickly to the top, where they could be skimmed off by hand. He imitated this motion mechanically in his purifier (Figure 89).

When the La Croixs first came to Minnesota, they tried to purify by more bolting, no doubt using flat sieves, since Nicholas became known as the "shaker miller." It was not long, however, before they had built purifiers for Faribault and the Archibalds, if not others, in which air was sent through a sieve shaken by mill power, along the general lines of Perrigault's machine. By this method they obtained less than 20 per cent of what is now called patent flour. In 1866 they built their own mill, but lost it when a freshet carried away the dam; they lacked capital, neither was much of a business man, and Nicholas was something of a spendthrift. In 1870 Edmund removed to Minneapolis, probably at the suggestion of George H. Christian, who as a flour broker visiting the Archibalds' mill had learned some of the secrets of its success and was eager to apply them in a mill of

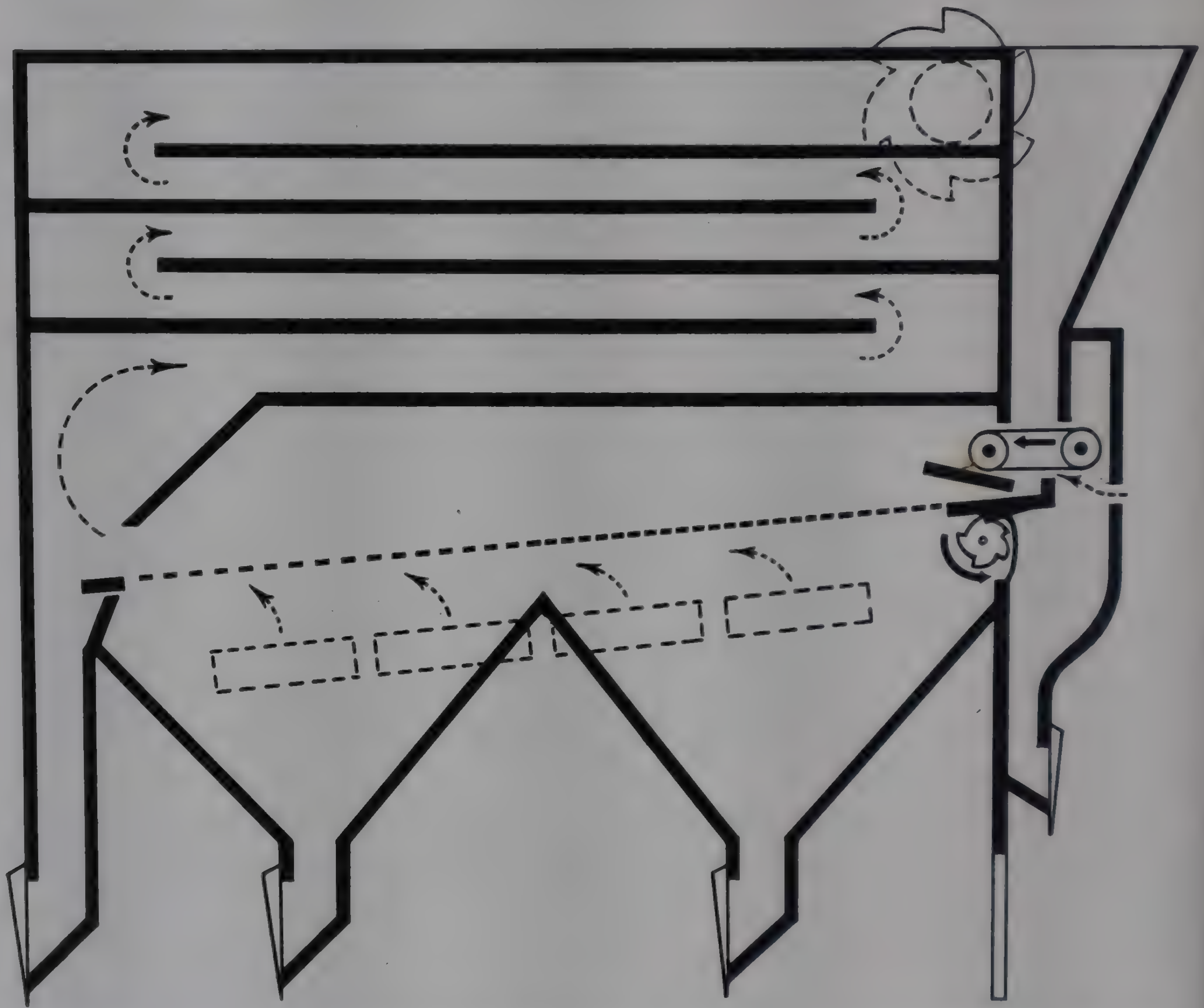


Figure 89. Perrigault's sieve purifier, patented in 1860, in which an exhaust fan drew air through a cam-agitated sieve. Four separations were effected – two grades of middlings through the meshes of the sieve, the larger tailings, and the lighter materials, which were carried up into a chamber fitted with baffle boards, where they were trapped for later removal. The baffles could be adjusted until the air leaving the chamber was relatively clear. The stock was subjected to an aspiration as it fell onto the sieve, and the hopper was fitted with a belt moving over rollers to serve the material evenly into the field of action of the air current.

his own. In Minneapolis La Croix was to play a decisive role in the solution of the purifier problem.

The Falls of St. Anthony had been named in 1680 by a French expedition exploring the upper Mississippi, and had been sketched by Jonathan Carver in November 1766 (Oval, Chapter XIV). It had a direct drop of about forty-five feet, plus nearly a mile of fairly rapid descent, over the same escarpment that produces Niagara and the Falls of the Genesee farther east. There are also many less spectacular drops in smaller rivers crossing this fall line. It was natural that such a magnificent power source as the Falls of St. Anthony should become a milling center, as soon as people, wheat, and a market were available.

The first mill in Minnesota had been set up by the Army in 1823 to the west of the Falls, in what was later the village of Minneapolis, and the first toll mill there had been erected in 1851. But substantial operations did not begin until Rollins, Eastman, and Upton erected a three-run mill on Hennepin Island in 1854. This mill, soon enlarged to five run, paid for its construction with 50 per cent over during the first year, and the saga of Minneapolis milling had begun. The demand for wheat was so great that it was shipped up the river from Iowa to St. Paul, whence it was hauled by team to the mill, at a total cost of about $1 a bushel. This was less than $5 per barrel of flour produced, and the flour sold for from $9 to $12. For a number of years this wheat was required to feed the local population, as was pointed out, rather caustically, by Horace Greeley in 1858: "I saw that your state imported not only loafers in great abundance, but the bread they ate as well as the whisky they drank."

But it was just about the time of this comment that Minnesota began to produce a surplus of wheat, and shortly thereafter was shipping flour east. In 1862, in order to meet the prejudice against the spring wheat of the region, Minneapolis flour reached eastern markets labeled "Muskingum Mills, Troy, Ohio—The Genuine." There was trouble in disposing of some parts of the grist. The farmers were not used to feeding their animals bran, so it was sold for the price of hay if it could be marketed at all; often it was simply thrown into the river. Nor could the middlings be easily sold, except as ground into "red dog" for the Indians. But the need of flour was so great that niceties of economy in production were for a time luxuries that could not be allowed to interfere with the rush of manufacture.

An immense source of energy like the Falls of St. Anthony cannot be utilized extensively until controlled portions of the water have been diverted into man-made channels, and charters for developing the power on the east and west sides of the Falls were granted in 1857. By that time a number of mills were already in operation at St. Anthony on the east side of the river, including the sawmills which had helped to provide capital for the flour mills. For this reason and because capital was lacking, the construction of a power canal there was delayed until 1880. The west side had been opened to settlement in 1856 and was incorporated as the town of Minneapolis in 1858. Here there was little to interfere with a prompt development of the site, and from then on Minneapolis took the lead over St. Anthony in a breath-taking growth which carried the town, soon to be a city, to the milling leadership first of the region, then of the United States, and very shortly of the world.

By 1860 there were about 5,900 people at the Falls, and 4 merchant flour mills; in 1865 there were 7 mills, and in 1869 13, while the population had doubled; the number of merchant wheat mills increased to a maximum of 26 in 1880, and by 1884 Minneapolis had passed Budapest to become the world's principal milling center. Flour production went on increasing until 1915:

	Barrels
1860	30,000
1865	98,000
1869	250,000
1875	843,000
1880	2,052,000
1885	5,973,000
1890	7,434,000
1895	12,577,000
1900	14,863,000
1910	15,813,000
1915	20,443,000
1920	17,118,000
1925	10,969,000

The size of American mills was increasing in all sections of the country, but nowhere more rapidly than in Minneapolis, where the average daily capacity per mill, which had been 25 barrels in 1860, rose to 1,837 barrels in 1890 and reached 3,623 barrels thirty years later.

In 1870–1871 St. Anthony's falls were given a wooden apron to protect them from destruction and recession, and by 1877 the platform over the falls had been described as "the most profitable manufacturing locality in the world." Minneapolis at that time had drawn alongside and was passing St. Louis, the soft-wheat milling capital, as the country's leading flour-manufacturing center in both quantity and quality of output. This prosperity had a double foundation: (1) Minneapolis had magnificent natural resources in her water power and in the hard spring wheat of the surrounding region – by 1874 two thirds of the tilled area of Minnesota was in wheat, and by 1877 over one half of our wheat crop for the first time was harvested west of the Mississippi; and (2) she had an abundance of milling talent, drawn to the location by its potentialities. These men solved many of the problems that had been puzzling millers since the art began, and would lead the world in methods of reduction, quality of output, command of local, national, and international markets, and competent organization of the entire milling business. Among them three persons were outstanding in energy, business acumen, and scope of imagination – C. C. Washburn and the Pillsburys, uncle and nephew.

Of these the eldest, Cadwallader Colden Washburn, had been born in Maine in 1818, and on reaching twenty-one had borrowed enough money to go west, where he taught school, clerked, surveyed land, set up a law office, and finally in 1844 began to lay the foundations of a fortune as a Wisconsin land agent. His personality and abilities rapidly won him wide reputation, and in 1854 he was elected to Congress, in which two brothers also sat as representatives from Maine and Illinois during his first three terms of service. In 1856 he participated in the organization of the Minneapolis Mill Company, and from that time on was a powerful factor in American and finally world milling. During the Civil War he raised a regiment of cavalry, and served as major-general in the Mississippi campaigns, including the fighting around Vicksburg. In 1871 the Washburn B mill led the way in the large-scale application of New-Process milling; in 1877, largely through Washburn's efforts, direct international trade in Minneapolis flour was firmly established; and in 1878 Washburn set aside a portion of his C mill for an experimental 150-barrel-per-day installation of an all roller system without millstones, at a time when roller milling was hardly more than a matter of hearsay to American millers. His great prestige guaranteed the new ideas a fair trial. He died in 1882.

The Pillsburys were born in New Hampshire, John Sargent in 1828, and his nephew, Charles Alfred, in 1842. John settled at St. Anthony in 1855, and soon had extensive lumber and real-estate interests, in addition to being a dealer in hardware. Charles in the meantime attended Dartmouth College and later clerked in a Montreal produce commission store. During the Civil War John Pillsbury helped organize the first three Minnesota regiments and began the first of a number of terms in the state senate. Later he was for three terms Governor of Minnesota; noted for his benefactions, for nearly forty years he powerfully furthered the growth of the state university. In 1869 Charles arrived in Minneapolis and purchased a share in a flour mill, and in 1872 John and he combined with other members of the family in a large-scale enterprise which was soon to include numerous mills. Charles was especially active in furthering the growth of Minneapolis through building railroads and by securing favorable freight rates, but he was also prominent in the introduction of roller milling and in extending foreign markets for American flour. Charles Pillsbury died in 1898; John Pillsbury in 1901.

Another important leader in Minneapolis milling was the George Christian who induced Edmund La Croix to come to the new center. Early in 1871 we find him entrusted with the remodeling of the Washburn B mill and including in his plans air purifiers of the Perrigault type constructed under La Croix's supervision. But the bolting cloth on La Croix's experimental machine clogged so badly that a man had to stand by to run a brush over its lower surface from time to time to keep it clean. George T. Smith, whom Christian had induced to leave a position with Gardner at Hastings, remedied this difficulty by using the feed-roll shaft of the machine to drive a brush under the cloth. Thereafter he noticed that the air currents were carrying many of the finer middlings away with the bran, to the loss of valuable flour material. He devised a "double machine" in which two sieves received middlings of different sizes graded by a reel, while a single fan drew air through both. Soon a "triple machine" was produced to purify three grades of middlings on three sieves. In a short time Smith set up in business as a purifier manufacturer; Figure 90 shows a cross section of his machine in its 1876 form.

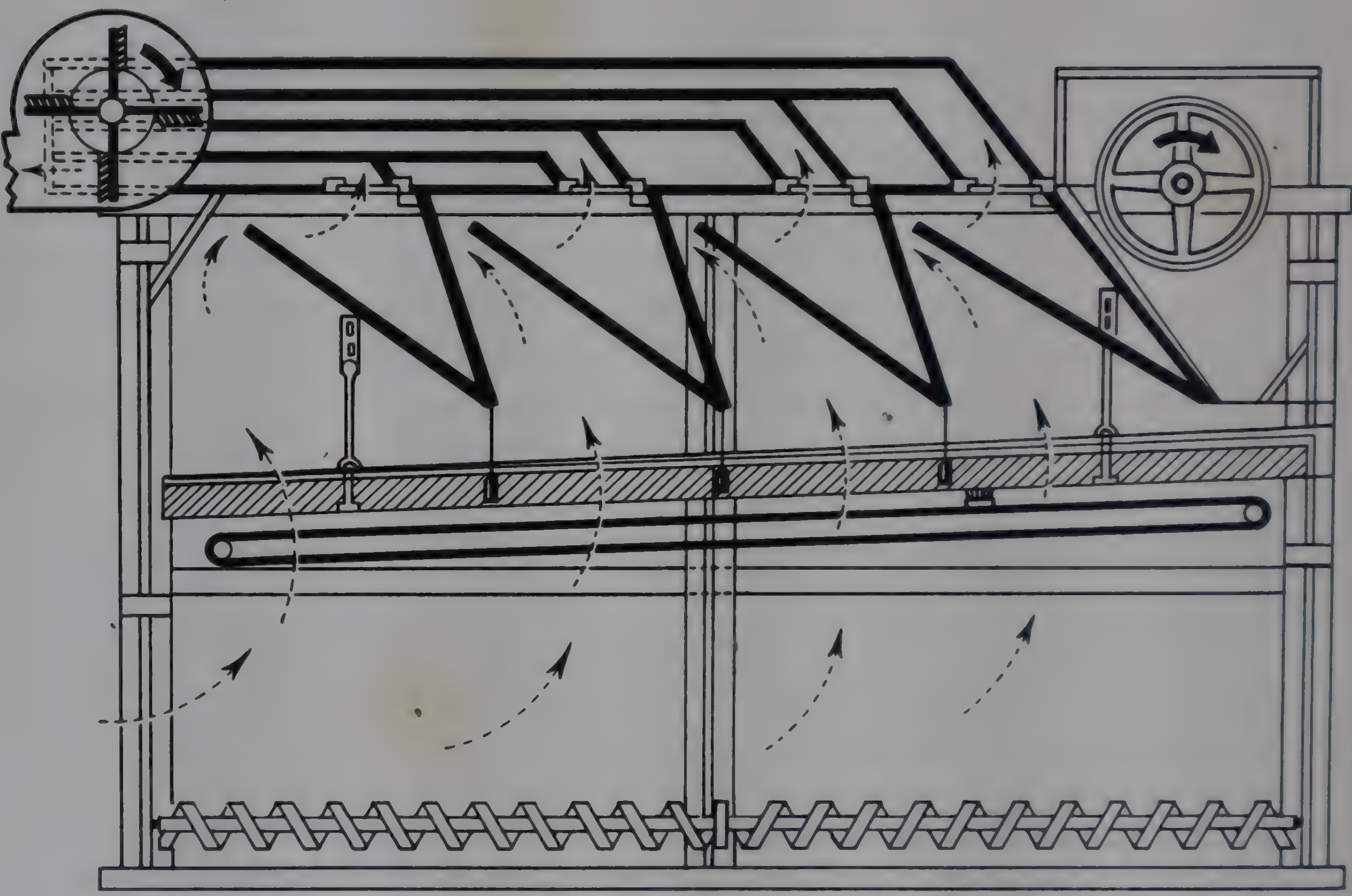


Figure 90. Smith's sieve purifier in its 1876 form, when large-scale manufacture was started. The stock was graded by a reel, shown at the upper right (not long enough to be very effective), and dropped onto two or three agitated sieves – only one can be seen in this head-on view. Air currents drawn up through the sieves lifted the lighter materials into a series of pockets, where they were deposited and could be inspected. Above the pockets were adjustment valves. A traveling brush, Smith's principal addition to La Croix's French-type purifier, kept the sieves clean from beneath. Since the brush traveled the length of the machine, instead of across it, it mixed fine stock with coarse. Conveyers at the bottom of the machine carried the purified middlings to exit spouts. The sieves were narrowed toward the tail of the machine in order to keep them sufficiently loaded.

The automatic cleaning brush was not the only respect in which Smith's purifier was an improvement on La Croix's machine: air currents were under better control, and the middlings were at least partially graded. There is no more clearly established principle in modern milling than that purifiers can handle stocks of but one size-range. The reason is now obvious: if the particles are of different sizes, air currents strong enough to lift the larger bits of almost pure bran will also carry away some of the smaller bits of pure or almost pure endosperm.

Largely under the influence of the refinements of Hungarian milling, purifiers and bolters were greatly multiplied in American mills, even before the introduction of rollers. What had happened here, as so often in the field of mechanical progress, was not that an exceptionally brilliant invention had been originated, but that a good idea had been given just those detailed refinements in practice which enable the invention to fit into a practical scheme of use. Good machines are produced mainly by the interrelated solution of a multitude of technical problems, and very seldom indeed by the application of utterly new principles. Purifying, for example, is only winnowing and sifting being carried on simultaneously, but mechanically and under careful control—conditions requiring improved mechanisms not only in the purifiers, but also in machines at earlier and later stages of the process. The noted German inventor Gustave Behrns in 1876 remarked that, compared to American machines, German purifiers "seem like playthings." Smith was as much responsible for this result as any single man, although La Croix undoubtedly first showed him the way, and many others followed his lead.

Smith's legal and business affairs were very cleverly handled in a series of patent wars, deals, and consolidations in the early 70's, but with the result that "it was not until 1876 that manufacture was commenced in good earnest." At that time only forty-two mills were actually using his machine, although its influence can easily be discerned in other purifiers. By 1880, however, 2,000 Smith purifiers were in use; in the next three years 7,000 were sold; while by 1892, 19,000 had been marketed. Nor was the boom confined to the Smith machine; dozens of purifiers were placed on the market, of many virtues or none, under well protected or infringing patents. By 1877, 280 purifier patents had been granted, and of all varieties, including finally at least two electric purifiers and one which sought to accomplish the separation by means of a beam of light in a vacuum, all three equally impractical.

The purifier became the principal factor in New-Process milling, and its widespread adoption was encouraged by the powerful influence of profit and loss. Its first effect was to produce a superior flour, even from our previously unpopular hard spring wheat; and here as in Hungary, this flour commanded a higher price. Of the Washburn B mill, where the puri-

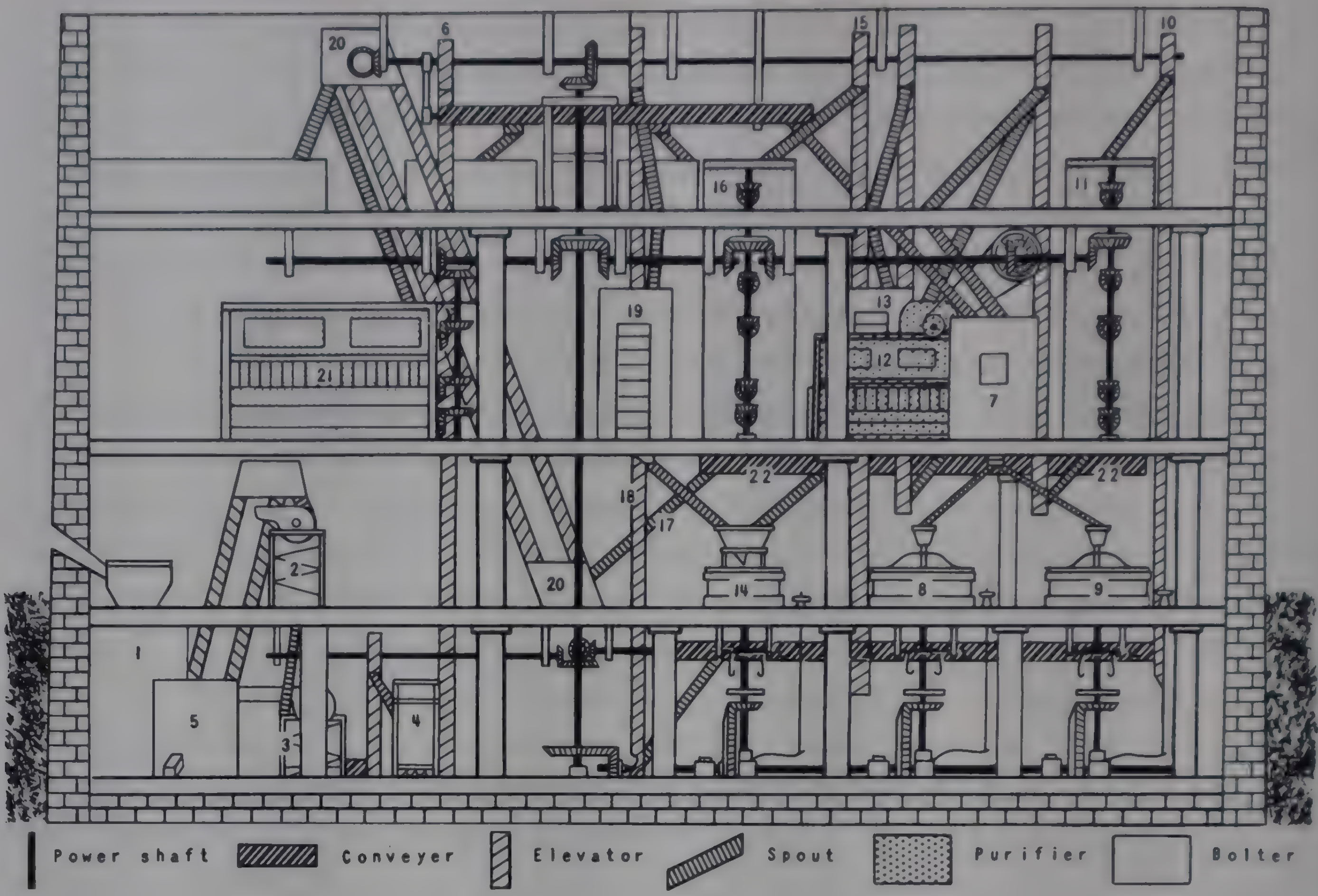


Figure 91. New-Process mill, using millstones and purifier, with an output of about 100 barrels a day; adapted from Dedrick. 1, receiving bin; 2, receiving separator, similar to Figure 81; 3, milling separator; 4, scourer, or smutter (*cf.* Figure 81); 5, dust room; 6, elevator for clean grain; 7, wheat garner over millstones 8 and 9; 10, meal elevator; 11, meal-bolting chest; 12, purifier; 13, middlings garner over middlings stone 14; 15, elevator for ground middlings; 16, middlings bolting chest; 17 and 18, spout and elevator for carrying tailings and rejected materials to 19, the second middlings bin; 20, elevator also connected with spout 17, for conveying these materials to reel 21; 22, conveyer for carrying flour from chests 11 and 16 by way of elevator 20 to a flour bin on the top floor.

fier first proved practical on a large scale, George Christian himself said: "Our profits for the first year of the 'New Process' were fifty cents a barrel, the second year they averaged a dollar a barrel, the third year two dollars a barrel." These were the premiums the American public with its strong preference for white flour was willing to pay for the greatly improved "patent" flours produced by the purifier. In 1873 the Washburn A mill was built in the most approved fashion of the day, largely out of purifier profits.

But thanks to the mechanization of milling here, the high prices were not permanent as in Hungary. The millers of Minnesota, like those of the Danube Valley, in dealing with a hard wheat had to grind higher to get a satisfactory flour, but from the first they placed greater reliance on machines. In contrast to the elaborate high-grinding methods of the Hungarians, involving much hand labor, American millers developed a less elaborate "half-high" grinding system, with a full panoply of conveyers, elevators, and other automatic devices. As a result the output of New-Process mills increased rapidly until the whole market could be supplied, other flours could be sold with difficulty, and the prices of patent flour declined sharply. Soon the entire American public could be served with a product comparable to the best grades made by Hungarian millers for the artistocracy only.

Figure 91 shows the cleaning and reduction layout of a characteristic small New-Process mill. The flour-packers and the large storage bins for grain, flour, and feed are not shown, nor is the water wheel; the mill is powered through the shaft just above the basement floor. We see here the increased attention American millers were giving to cleaning the grain before grinding.

Brush machines to rub off the dirt and loose bran were used in many mills in addition to, or instead of, separators and smutters, as well as cockle machines or oat extractors similar to the *trieur* of Figure 82. "Disintegrators" were also tried for grain-cleaning or sometimes for breaking it up (Figure 92). But they wasted power, and although they made excellent large middlings from which a first-rate flour could be ground, they also made large amounts of flour which was completely dead because the very life had been beaten out of it. In 1878, when the wire binder had become popular on western farms, Charles Espenschied was the first to add magnetic separators to the mill—sets of magnets in a box placed where the grain was in motion. Modern mills almost invariably use magnets, improved by automatic arrangements to remove the tramp iron as it accumulates.

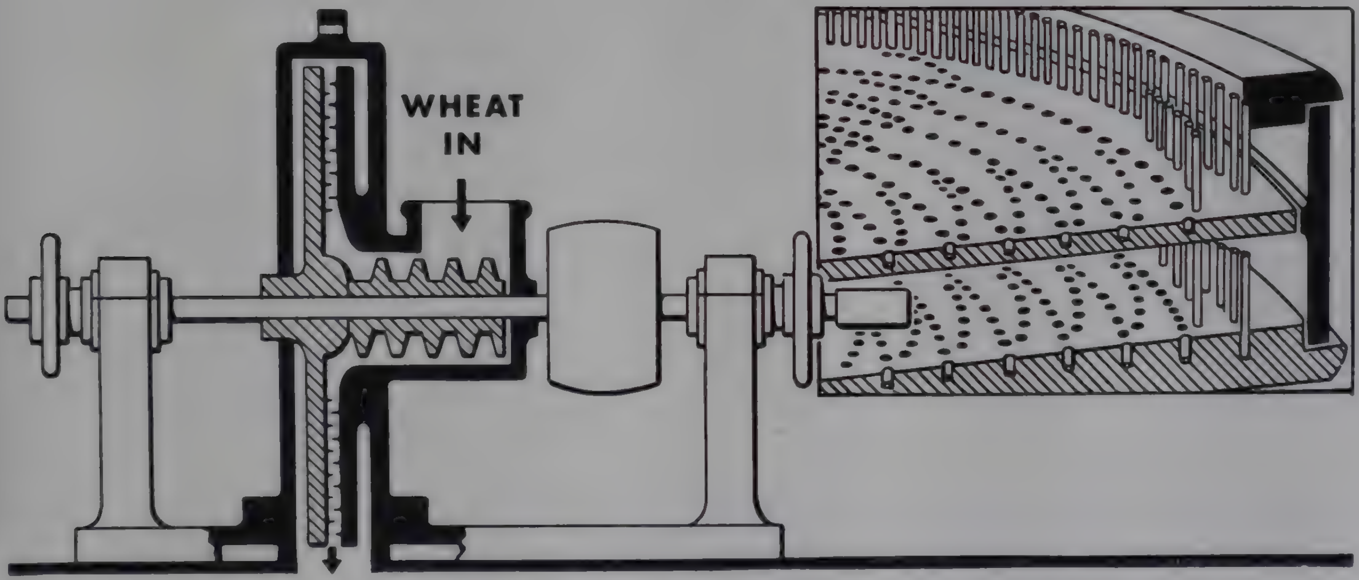


Figure 92. At the left, the working parts of a "disintegrator" in cross section. A conveyer served the grain into the eye of a rapidly rotating disk, where it was thrown by centrifugal force into a narrow, pin-studded space for cleaning or reduction. At the right, a portion of a machine working on the same principle, with most of the pins removed—Jonathan Mills' bran duster, used at the tail of the mill to knock off small quantities of flour still adhering to flakes of bran.

There was a lively controversy right through the 70's and early 80's between those who believed in a thorough, even severe cleaning and those who advocated less extreme measures. Inventors, and millers after them, pursued the "crease dirt" of the wheat kernel to its lair, and in cleaning the berry removed up to 5 per cent of good flour as well. There were even those who sought ways to split the berry in two. Most American millers finally settled the cleaning question by a procedure which "handles the wheat gently, atoning for the slight action of the machinery on the wheat by a number of operations, or by the length of time during which the wheat is subjected to the manipulation of the cleaning apparatus." This conclusion could more easily be carried out here, where practically all mills of any size were automatic, than in Europe, where sketchier cleaning systems were the rule.

The New Process made little use of washing in wheat-cleaning. An immense amount of water would have been required, in terms of the available supplies; and in addition, wheat-wetting is still a ticklish proposi-

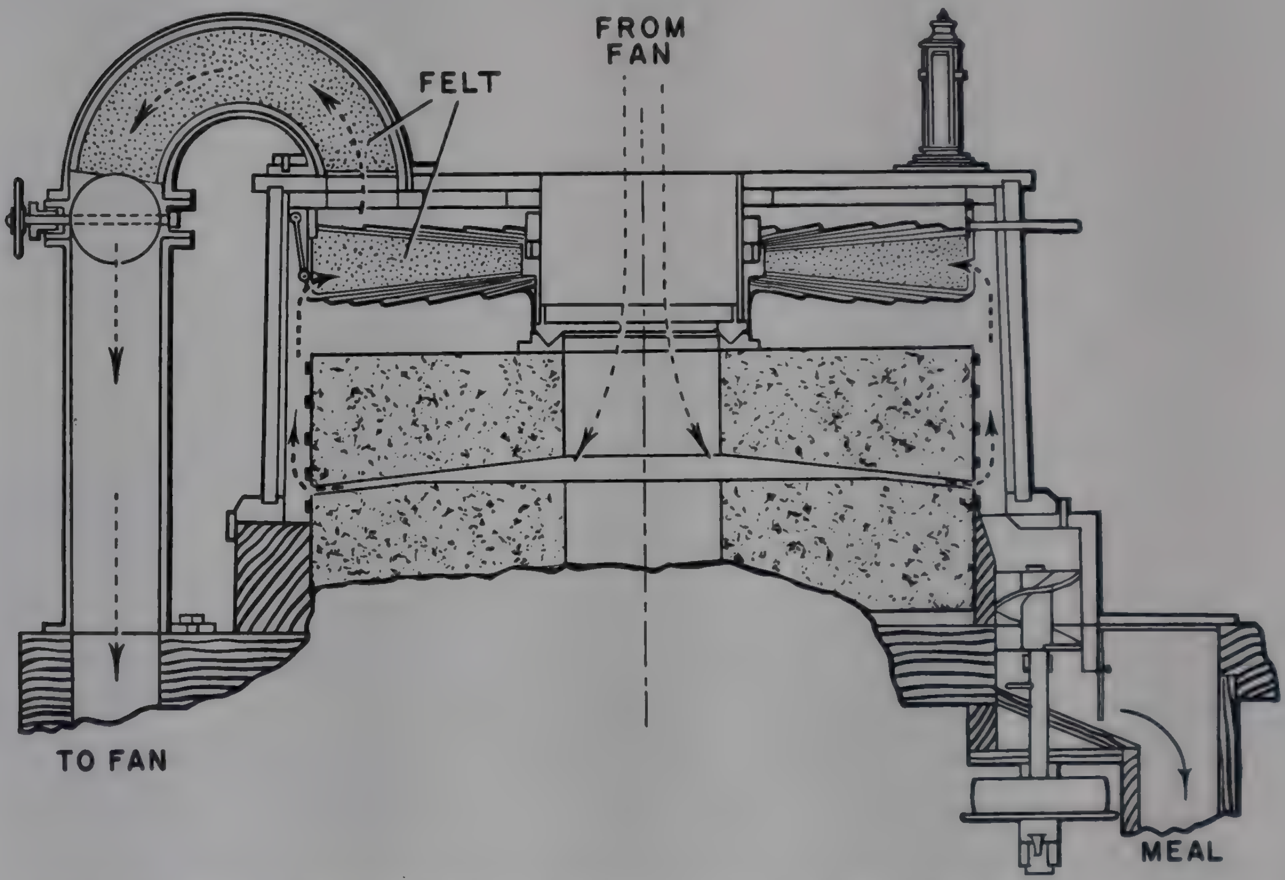


Figure 93. The Brehmer-Behrns millstone exhaust, in which an air current was drawn between the stones and through a cloth filter, where the dust was deposited. A spiral passage at the point where the meal left the stones prevented the loss of air. From time to time the exhaust was temporarily turned off, and a workman pressed on the protruding bar at the upper right to clean the filter. The air discharge pipe had to be lined with felt for some distance from the millstones, to discourage condensation. By 1880, 3,200 of these devices had been installed in American mills, besides many more abroad, where the apparatus had been developed in Germany.

tion even today, with all our increased knowledge and improved controls. Wheat had often to be damped to toughen the bran both here and abroad, even during the days of low grinding — a step toward tempering, or conditioning. In American mills the dampening usually took place while the wheat was being moved into a conveyer. The process was so haphazard that the flour often fermented and could not be kept for long or shipped to distant markets. Bakers objected to the wetting of wheat, on the ground of injury to the flour, and because they did not want to buy water at the price of flour.

The Dedrick mill of Figure 91 ground with three pairs of stones of small diameter — 48 and 36 inches, as compared with the 5-foot stones of the Old Process — set to run fairly far apart at slower speeds than formerly. New-Process stones were dressed with more furrows and less land area and were often hollowed out for some distance away from the eye; the lands themselves were less roughened, so that they did less grinding and were naturally better ventilated; but in addition the stones, like the ones pictured, were often fitted with an exhaust — an ingenious device which circulated air from a fan between them without loss of any of the grind (Figure 93). With such an exhaust, water to the amount of several buckets might be drawn off from a single stone in twenty-four hours. This gave a much drier flour, and made it unnecessary to cool the grind.

On New-Process stones as little as 4½ bushels an hour might be ground, although the more usual figure was about 8 bushels, as compared with the 15 bushels or more of the Old Process. The effort was to make as many middlings as possible, consistent with the maximum production of flour of the best salable quality by the remaining operations of the mills. Whereas only from 3 to 5 per cent of middlings had been produced in Evans' day, under the New Process this figure was quickly increased to 20 per cent; eventually perhaps 60 per cent of middlings was produced for reduction to flour in well-run mills. With rollers today, nearly 75 per cent of the cleaned grain reaches the purifiers.

It will be noticed that New-Process milling required a great increase in bolting surface (Figure 94). This came about through conscientious application of the fundamental principles of all bolting, which were clarified in New-Process days: (1) remove all impurities, and all finished products, as made; (2) grade all materials. Though the mill we have just described had only two run of wheat stones and one pair of middling stones, it required seven reels in three chests to do its bolting. A New-Process mill with eight run of wheat stones might easily include thirty or more reels, in perhaps ten chests of considerable bulk, running through two or more floors of the mill. Each of these reels had to be expensively clothed, and demanded constant attention — bolters offered admirable opportunities for insect infestation or dough formation, and if the cloths were

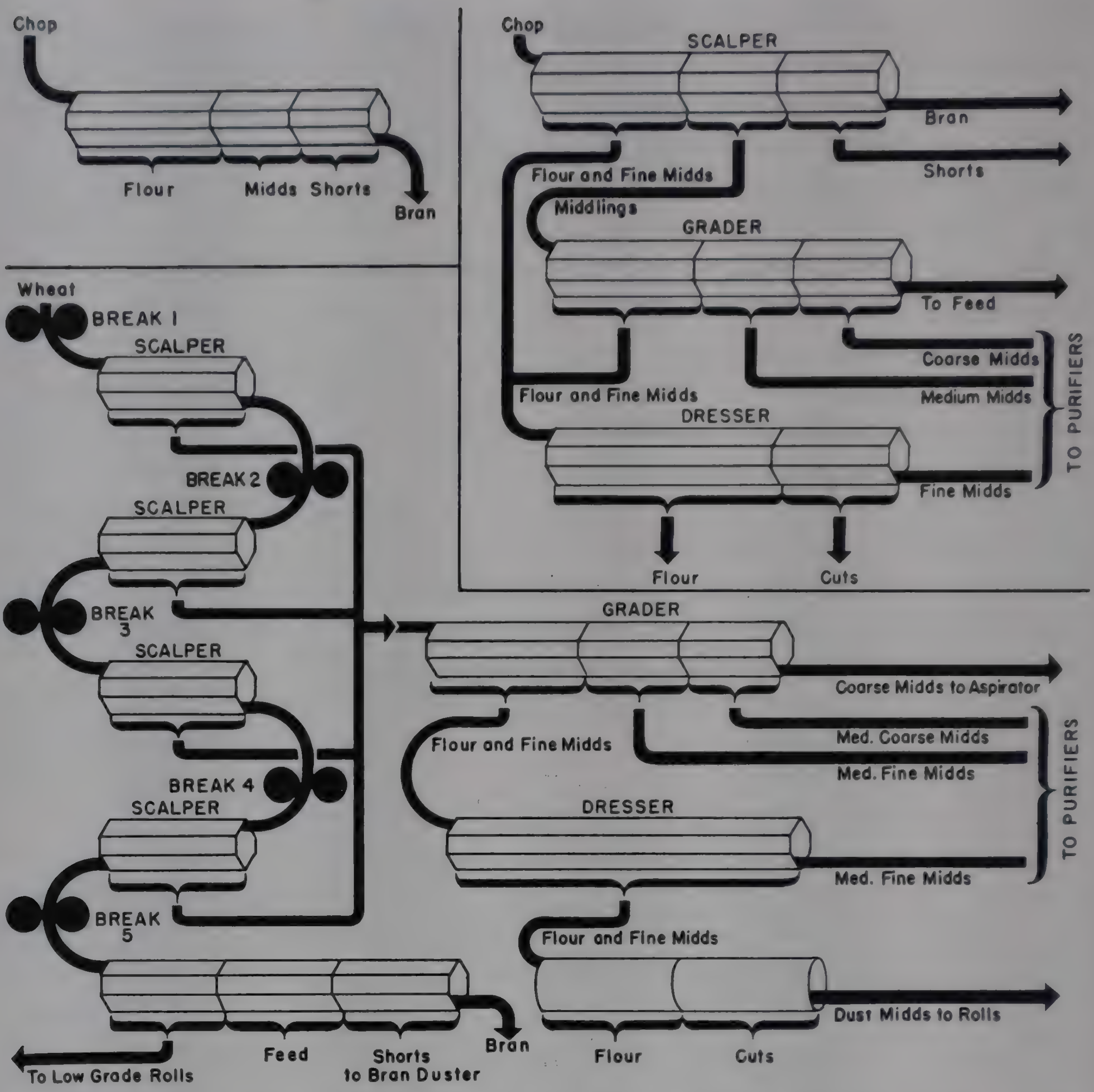

Chop
Flour
Midds
Shorts
Bran
Chop
SCALPER
Bran
Shorts
Flour and Fine Midds
Middlings
GRADER
To Feed
Coarse Midds
Medium Midds
Flour and Fine Midds
DRESSER
Fine Midds
TO PURIFIERS
Flour
Cuts
Wheat
BREAK 1
SCALPER
BREAK 2
SCALPER
BREAK 3
SCALPER
BREAK 4
SCALPER
BREAK 5
GRADER
Coarse Midds to Aspirator
Flour and Fine Midds
Med. Coarse Midds
Med. Fine Midds
DRESSER
Med. Fine Midds
TO PURIFIERS
Flour and Fine Midds
Dust Midds to Rolls
To Low Grade Rolls
Feed
Shorts to Bran Duster
Bran
Flour
Cuts

Figure 94. Break bolting systems. Upper left, an Old-Process hexagonal bolter. Upper right, a simple New-Process system, consisting of a scalper to tail off the coarser contents of the chop, a grader to size the middlings, and a dresser to separate out whatever flour was made by the millstones. Scalping improved the stock by immediately removing potentially contaminating materials; grading was necessary to get uniform purifier stocks. Below, a simple break bolting system for use with roller units. After each break the material was scalped before being sent to the next break. The throughs of these scalpings were accumulated for grading and dressing, a procedure which would not be followed today. In this system hexagonal reels were used throughout, except for the cylindrical flour reel. In New-Process and roller mills further elaborate bolting systems were required after the stock had passed through purifiers and reduction stones or rollers.

torn could confound the entire scheme of separations. Care had to be taken that each reel receive sufficient material, or impurities would work through; but not too much, or the material would not be thoroughly graded. While the hexagonal reel was a considerable improvement over the round reel – it tumbled the stock over the bolting surface, rather than making it slide on it, thereby encouraging higher grinding by its success in treating coarser stocks – the danger of specky flour from underloaded hexagonals also encouraged the unwise policy of returns.

The problem of devising an improved method of bolting was urgent in New-Process milling, but it became unavoidable with the advent of roller milling. In the Washburn A mill of 1878, for example, which used both rollers and millstones to produce 1,700 barrels of flour per day in the one half of the mill completed at that time, there were 148 enormous bolting reels occupying two complete floors. The solution of the bolting problem was not achieved, so far as the United States was concerned, until after the introduction of rollers.

Another perhaps less obvious problem lay in the handling of branny stocks at the tail of the mill. These stocks contained considerable flour, which the New-Process miller was forced to send to the feed bag for want of a satisfactory method of recovery. In the mill of Figure 91, these stocks were handled by only a single bolting reel, if at all. Bran dusters more or less similar in cross section to the one shown in Figure 82 were often used to brush the flour off the bran particles and drive it through the walls of a cylindrical bolter; but the difficulty lay rather in the abundance of these branny materials than in the best manner of treating them after they had been made. Even today some remnants of the problem of tail stocks remain, although once more the introduction of rollers mitigated the difficulty.

New-Process mills became increasingly dangerous as they grew in size because of the great quantities of dust produced and spread through the mill by its many operations. In one of the largest mills, the Washburn A, the pride of the New Process, 3,000 pounds of dust were collected every day from two dust rooms on a floor underneath the millstones (Figure 95). While every effort was made to control the dust so as to protect the workers from "miller's cough" and to recover economically valuable contents, the only known procedure was to exhaust the many fans into such isolated rooms. This increased the fearful and little-understood hazard of explosion. Finely divided particles of any oxidizable substance, including not only flour-mill dusts but even such materials as iron filings, under favorable conditions will ignite and burn so rapidly that the gases released have explosive force. If the flour in a hundred-pound sack were evenly dispersed in a confined room 20 feet square and ignited, a force sufficient to lift a warehouse and 20,000 barrels of flour 100 feet into the air would be released. And so as mills increased in size, "fires," always a mill hazard, became more numerous and more devastating – so much so that mill insurance presented an unwelcome, because unpredictably large, risk to underwriters.

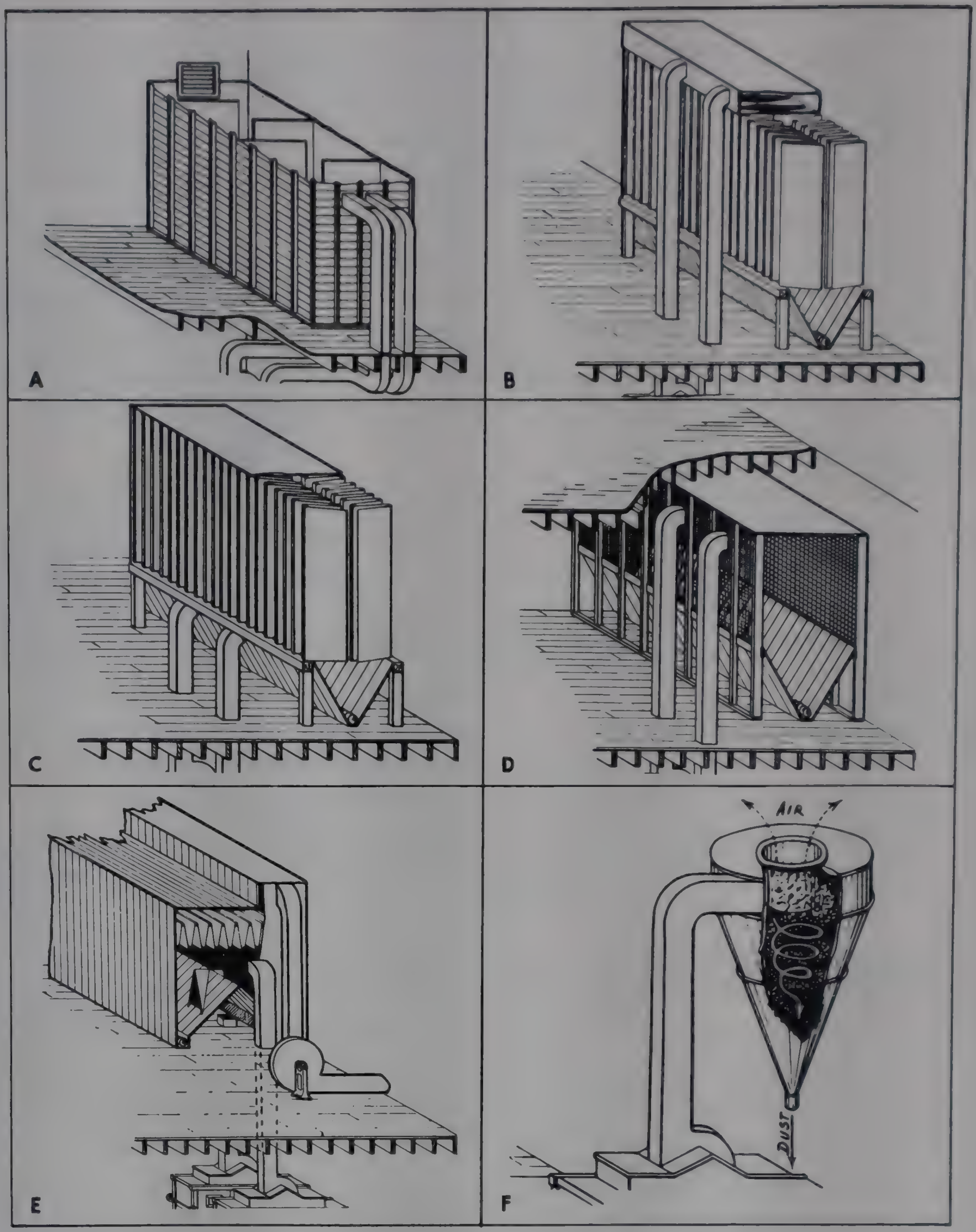


Figure 95. Types of dust collector. A, a dust room with baffles to encourage precipitation of the dust. B, a chamber filled with crisscrossed textile filters, with a conveyer below to carry out the dust. C, the same type, but with the dust-laden air entering from below the filters. D, a more easily cleaned chamber, with walls of gauze material. E, a chamber essentially similar to that in the Washburn dust collector (Figure 96), with its own exhaust fan over the textile filter. F, the cyclone type of collector, introduced in the middle 80's, in which the dust is brought to rest by friction against the side of the cone. Cyclone dust collectors are still in common use.

The dust problem was given frightful emphasis when, a little after seven o'clock on the evening of May 2, 1878, the Washburn A New-Process mill blew up, carrying to destruction five other of the country's best mills. As was usual in such cases, a small initiating explosion shook accumulated dust from the walls and ceiling, and was almost immediately followed by at least one other far more destructive blast. The force of the explosion razed the solid walls, six feet thick at the base, to their very foundations. The mills were not heavily manned at the time, so that only eighteen lost their lives, including all of the fourteen who were in the Washburn mill. It was concluded that one or more of the millstones must have run dry, making a spark which started the fearful disaster.

In an interview following the explosion, Governor Washburn announced his plan to rebuild, and stated: "In the new structure I shall adopt the Hungarian system of gradual reduction using rollers, and shall dispense

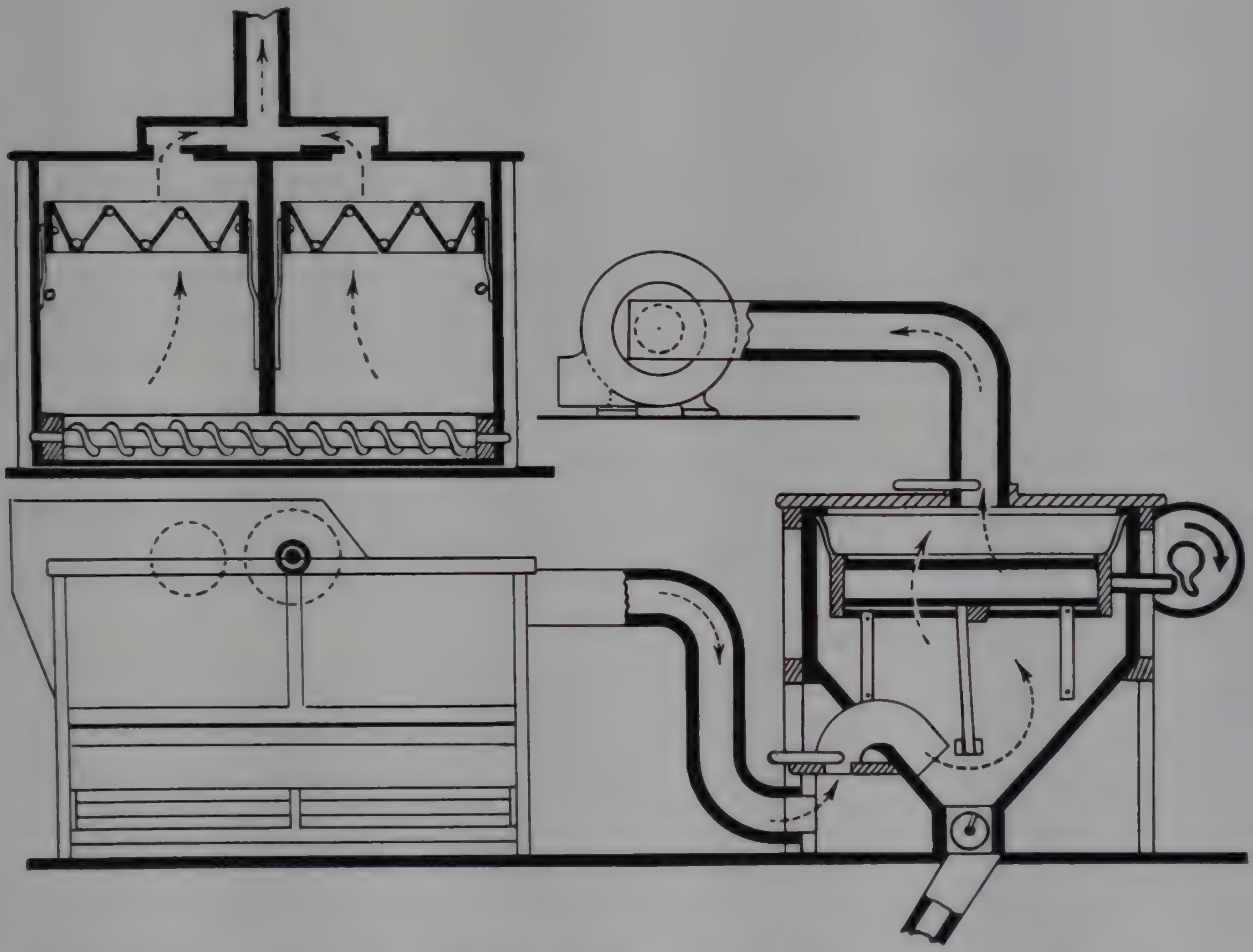
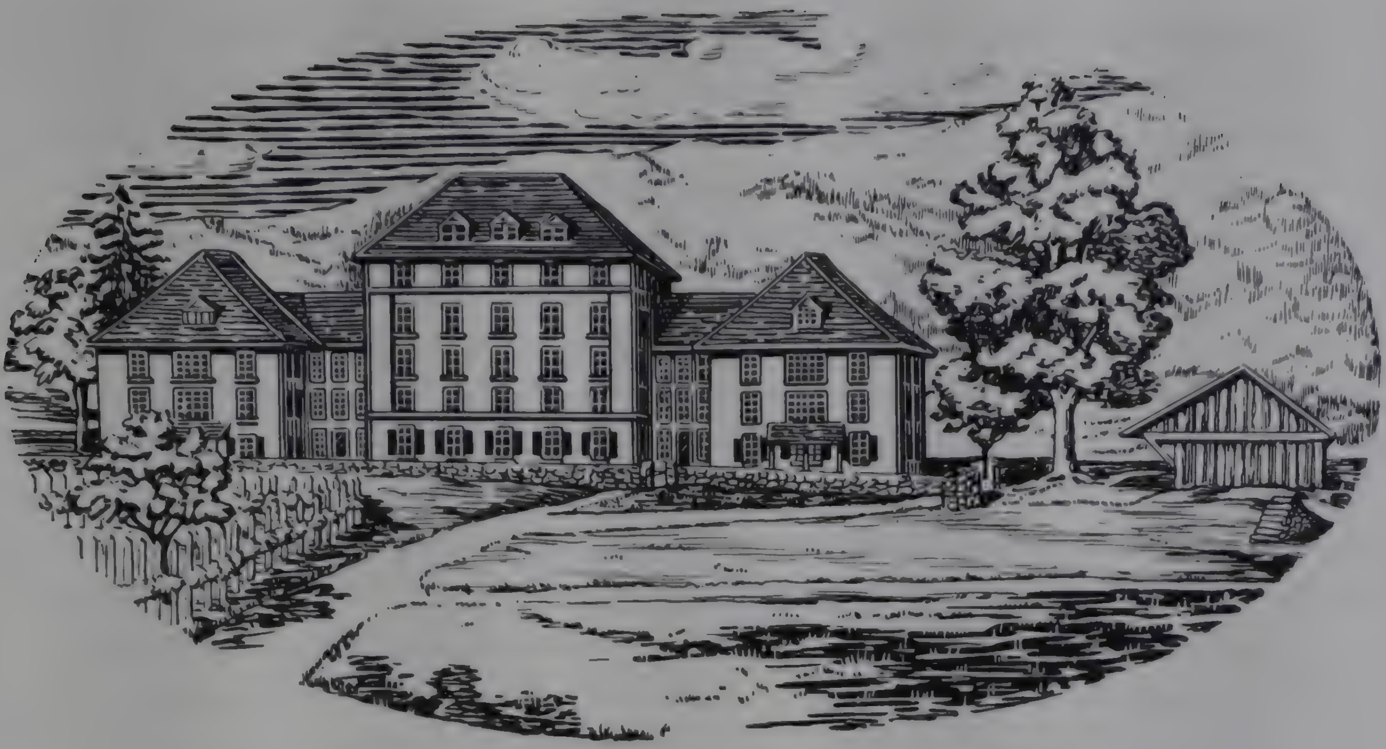


Figure 96. Washburn dust collector, in its form as attached to a purifier or other machine. The dust-laden air entered the machine through a curved pipe at the bottom and was drawn upward by an exhaust fan. The dust was deposited on a cloth filter, shown in greater detail at the upper left. From time to time these filters were compressed, releasing the dust into a conveyer at the bottom of the machine. While this was happening the intake valve of the machine had to be closed. For a diagram showing the Washburn dust collector as used in a dust room, see Figure 95.

with a great amount of machinery heretofore used, substituting hand labor, which is safer, and I am not sure but it is also more economical. I propose to build for an abundance of room and thorough ventilation."

In the 1880 mill which the Governor constructed to replace the one destroyed, not quite all these plans were carried out. As we shall see, the new mill was still automatic and only partially given over to rollers; but it contained no fewer than thirty-eight dust rooms, in place of the two of the old mill, and notably more open spaces. The dust problem was augmented by roller milling, and its solution had to be placed high on the agenda of the late 70's and 80's. The Governor himself became greatly interested in it, and in 1879 secured a patent for an apparatus to collect mill dust (Figure 96).

Another great problem, and the one which offered the greatest opportunity for advance, lay in the fact that purifiers could use more highly differentiated materials than millstones could send them. A great many millstones of different set might have been used to produce a sufficient variety and amount of products to serve a battery of purifiers, after careful separations; but such an arrangement, actually employed in Hungary, used both time and space inefficiently. New-Process millers were faced by somewhat contradictory requirements: to make more middlings they must grind high; to clean the bran they must grind low. To these problems there were two related answers: the multiplication of processes, with finer adjustments, or in other words gradual reduction; and the use of rollers instead of millstones. These solutions constitute the next important phase of milling progress.



CHAPTER XV

Rollers and Gradual Reduction Advance the Milling Revolution

> There is hardly one thing in a modern flour mill in common with the mill of twenty-five years ago. The historic millstone that was considered by all millers of former days as being the life and heart of the mill, has given way to rolls, an entirely new creation.
>
> –W. D. Gray (1899)

THE millstone miller had always needed not only a sensitive thumb and eye and ear to get good flour, but a canny awareness of the special quirks of his mill – mills were always spoken of in the feminine, being creatures of personality, mood, and temperament – but his need for this combination of judgment and intuition was greatly increased by the multiplication of processes under high grinding. One reason why the New Process could not long endure unchanged lay in these excessive demands it made on the miller. The milling periodicals of the 70's and 80's are full of anxious letters from correspondents who are sure that they have arranged everything correctly, and still "there are specks in my flour," "I require five bushels of wheat to make a barrel of flour," "my reels paste up," "I am using double

Chapter head oval. Mill at Frauenfeld, Switzerland, where rollers were first used successfully, by Sulzberger in 1834.

the power of So-and-so's mill." The trials of New-Process milling for some were as great as its rewards for others.

The crux of the problem lay in the stones. An average bushel of clean 60-pound wheat contains about 800,000 grains of various lengths and thicknesses, and all these would pass between stones set for high grinding in about eight minutes. Well over 1,500 grains a second must enter and leave the grinding space, and in the course of a roughly spiral travel of 60 inches or more, must be broken and rebroken several times over to prepare them for the bolting, purifying, middlings-reduction, and final separations that followed. New-Process millstones, like those of low-grinding days, manufactured a variety of materials all at once: they were multi-product machines feeding materials to more specialized apparatus farther along in the process. A slight change in grinding conditions could throw the later operations out of balance. Trouble might be caused by harder or softer wheats or by an alteration in their cleanness or moisture content, by slower or quicker feed, stones out of balance, a change in speed of rotation, a variation in mill temperature. The New-Process mill was automatic, all right, but the miller must stand guard over it with unceasing watchfulness.

And yet the millstones were triumphs of skilled selection and construction: made of matched pieces of carefully chosen stones of exactly the right texture and surface, they were dressed with extreme care and were run in accurate equilibrium at well-determined speeds on ingeniously flexible rynd balances. To many a miller the millstone was the symbol of his art, and no ordinary piece of equipment in the same class with the rest of his apparatus. His reluctance to accept rollers in place of millstones was due largely to loyalty to a trusted device, and only in part to suspicion of the novel: millers simply preferred to keep their familiar millstones.

Cylindrical rollers turning toward each other had been used to flatten metals in the mints of northern Italy since the late sixteenth century, and were largely employed throughout western Europe by the eighteenth century for rolling metal sheets and bars. Rollers were also very early used to crush sugar cane, and we have already described the early hand-operated roller mills of Ramelli and Böckler (Figures 66 and 54). These machines were inferior to millstones in two important particulars: they were not adapted to quantity production, and the mounting of the grinding surfaces with respect to each other may have been accurate but was not flexible. Flexibility of mounting was necessary to allow for irregularities in the flow of stock, and even for occasional bits of metal and the like which must pass between the grinding surfaces without jamming, and this had been achieved in millstones. A runner stone in good balance did not touch the under stone during rotation, but it was not held stiffly in a single plane, as in Hungarian stiff-mounted gradual-reduction mills. It could tilt a bit on the rynd when necessary, the particles of wheat between the stones acting as crude roller bearings, while centrifugal force acting on its mass tended to restore it to its proper plane. Old millers used to say that the weight of the runner on its mechanical bearings was lessened by one hundredweight for each bushel of grain added to the hourly rate of grinding. There could be no such accommodation of pressure between stones held firmly by stiff rynds, or between rollers rigidly mounted.

Powered roller mills that could handle quantities of stock in a fairly satisfactory manner and that could stand up under the rigorous requirements of large-scale production were devised long before the problem of flexible, yet accurate, roller mountings was solved. As is usual in our subject, the early accounts are contradictory and confused. Passing over a considerable number of early attempts that were fruitless for one reason or another, we come to 1830, when Müller, a Swiss, persuaded a group of his compatriots to back a roller-mill project along the lines of an enterprise he claimed to own at Warsaw. The Warsaw mill was probably chimerical, but in 1833 Müller completed at Frauenfeld a five-story mill (Oval, Chapter XV) with sets of rollers on every floor, from break rolls at the top to finishing rolls on the first floor.

He is said to have used a variation of a machine first put out by Helfenberger of Switzerland about 1820 and shortly afterward improved by the brothers Bollinger of Vienna. The Bollingers' machine had three small-grooved rollers set close together in triangular formation; the lower roller was geared to one of the others, and the two upper were adjustable, though nonflexible, and were driven by pulleys to run at 32 and 40 revolutions per minute respectively, a much slower speed than was used thereafter. This machine was awkward in that three near contacts were required, although only two of them could be used for grinding, since the lower roller of necessity could rotate toward only one of the upper rollers and served principally as a saddle or separator. In addition, rolls that would stand up in service were not obtainable.

When Müller's mill almost immediately failed, a Swiss engineer, named Jakob Sulzberger, who had assisted in its erection, was given the task of reconstructing the system. He instituted two important changes. He gathered all the roller sets on the lowest floor, close to the source of power, where their vibration would cause a minimum of trouble. There roller sets have stayed in practically all succeeding mill designs. Secondly, he devised a machine which, whatever its faults, was economical of materials and space, could easily be powered, and gave the stock a clean flow (Figure 97). He placed three pairs of rolls in a vertical column in a single case, and dropped the stock straight down through all three, without intermediate treatment. The small size of the rolls — 6 inches long — their inability to retract under heavy pressure and their need of scrapers which were less difficult to adjust, the slight differential in their rotation, the power

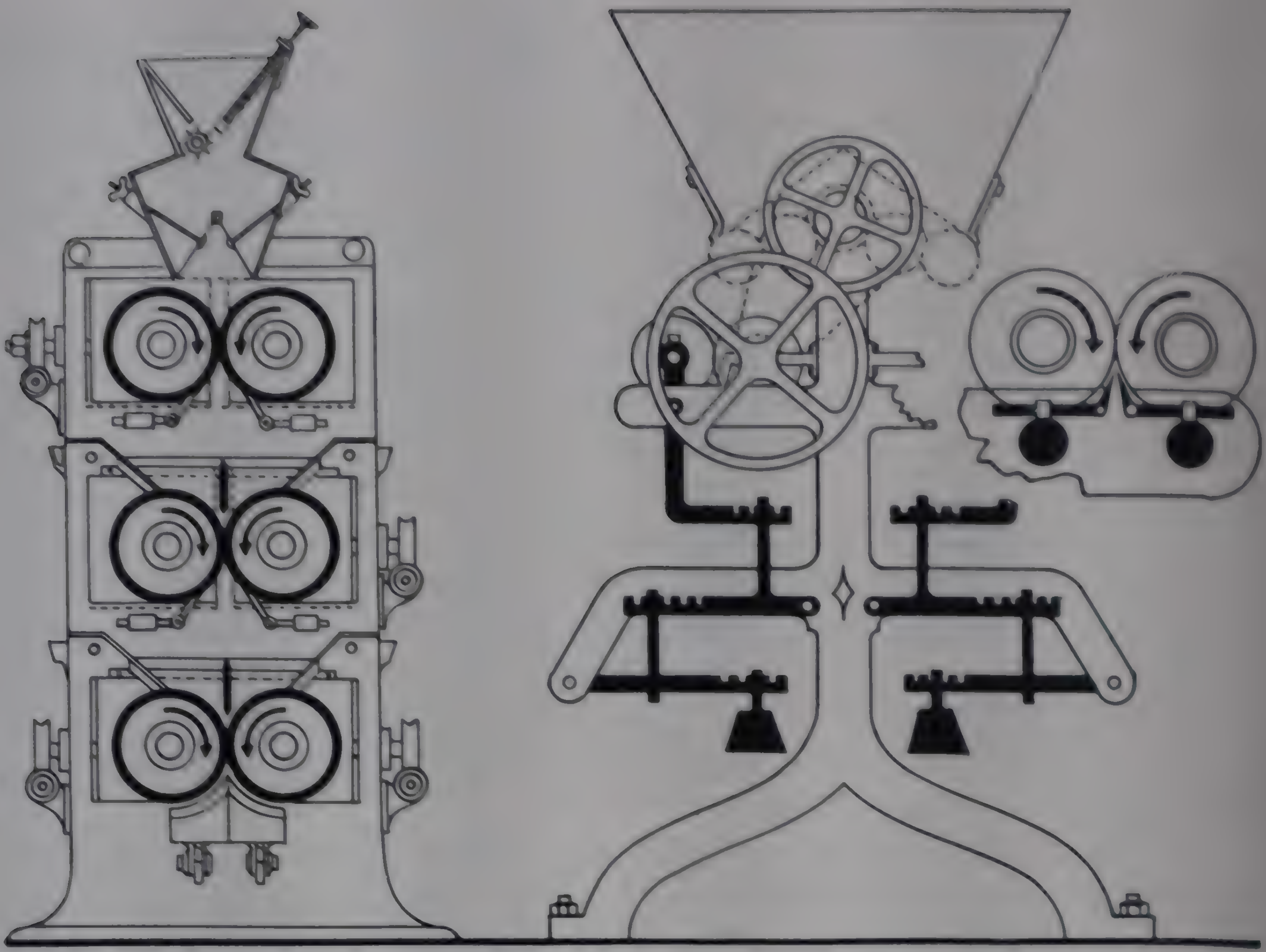


Figure 97. At the left, the first really successful and widely used roller assembly, that of Jakob Sulzberger (1834). The stock traveled between all three pairs of cast-iron rollers, and left them "very hot and flattened out like a sheet of paper." The machine illustrated was used to break the grain, all three pairs of rollers being corrugated and having scrapers. Machines for reducing the middlings thus made had two pairs of smooth rolls at the top, without scrapers. Thus we find Sulzberger distinguishing between the break and reduction sections of the mill, though without making further differentiations in either. The distance between the rollers could be adjusted, but they were firmly held, without give under an increase in pressure. This defect was first successfully remedied in Friedrich Wegmann's roller assembly (1873), shown in the right half of the figure, in which a weighted system of levers was used to keep the rolls in contact through the stock. These rolls also required scrapers, shown in the insert at the right. Note that each machine had an arrangement in the hopper for securing an even feed.

used and the care required by the machine, and the noisy gearing—all were serious faults; but the greatest fault was that the stock ran through all three pairs of rolls without bolting or purifying in between.

At the same time, Sulzberger was able to contract to deliver 72 per cent of high-grade flours, of which, however, but 12 per cent was of the very best quality. His process was so successful that his company established roller mills at a number of points in Italy and central Europe, including Kriens in Switzerland, Melegnano and Venice in Italy, Munich, Stettin, Leipzig, and Mannheim in Germany, and, in 1839, at Budapest in Hungary. Since Sulzberger's Budapest installation in the *Josef Walzmühle*, later incorporated as the *Pester Walzmühle Gesellschaft*, a continuity of roller milling has been maintained there right down to the present.

The old part of the mill was arranged in five sections, each having fourteen roller sets with three pairs of rolls each of the kind described, requiring altogether 300 indicated horsepower. Two of these sections manufactured middlings and semolina ("sizings," or large middlings), while three reduced these products to flour after bolting and purification. The Budapest mill was the first to use rollers both to produce middlings and to reduce them to flour, but millstones were still employed for a final cleaning of the bran at the tail of the mill. It was in this order generally—for breaking, middlings reduction, bran cleaning—that rolls were introduced into American mills.

It must not be imagined that even the few Sulzberger roller mills were exceptionally prosperous in the period from the 1830's to the 60's; one by one most of them closed because they were so costly to run and maintain. Using 36 roller sets and 28 workers, for example, the Ludwig mill in Munich produced 13,000 Bavarian bushels of flour per year, whereas with 13 pairs of millstones and 9 workers it was later able to turn out 26,000 bushels, or over six times as much per worker. No doubt the untrained and inexperienced millers were not up to coaxing good production out of Sulzberger's difficult apparatus. Even at Budapest, where the hard winter wheat made conditions especially favorable, there was no tendency for roller milling to spread until 1864, when F. Naeff developed an improved form of the Sulzberger machine for a mill near Fiume, at the head of the Adriatic. He simplified the drive, increased the size of the rolls to 9 inches, and considerably reduced the speed of rotation. The growth of the Hungarian gradual-reduction system, using rollers, dates from this time.

A rapid expansion of both economic and intellectual activity occurred in Hungary under the impetus of the autonomy granted to the realm by the formation of the Dual Monarchy with Austria in 1867. Whereas but one merchant flour mill had been added to the original roller mill at Budapest between 1839 and 1867, nine others were constructed between then and 1880; since that time but three more have been added. When the Budapest roller mill erected by Sulzberger was enlarged in 1868–1869, the addition was engineered by Oscar Oexle, and forty sets of Naeff's improved assemblies were added. By 1870 rollers were being used, along with millstones, by four other mills in and around Budapest, although it has been anonymously stated, without definite proof, that the Sulzberger mill no longer used millstones after its enlargement in 1869. This was almost certainly not the case in the old part of the mill when it was visited in 1879 by W. D. Gray, a celebrated American inventor and mill-builder. His

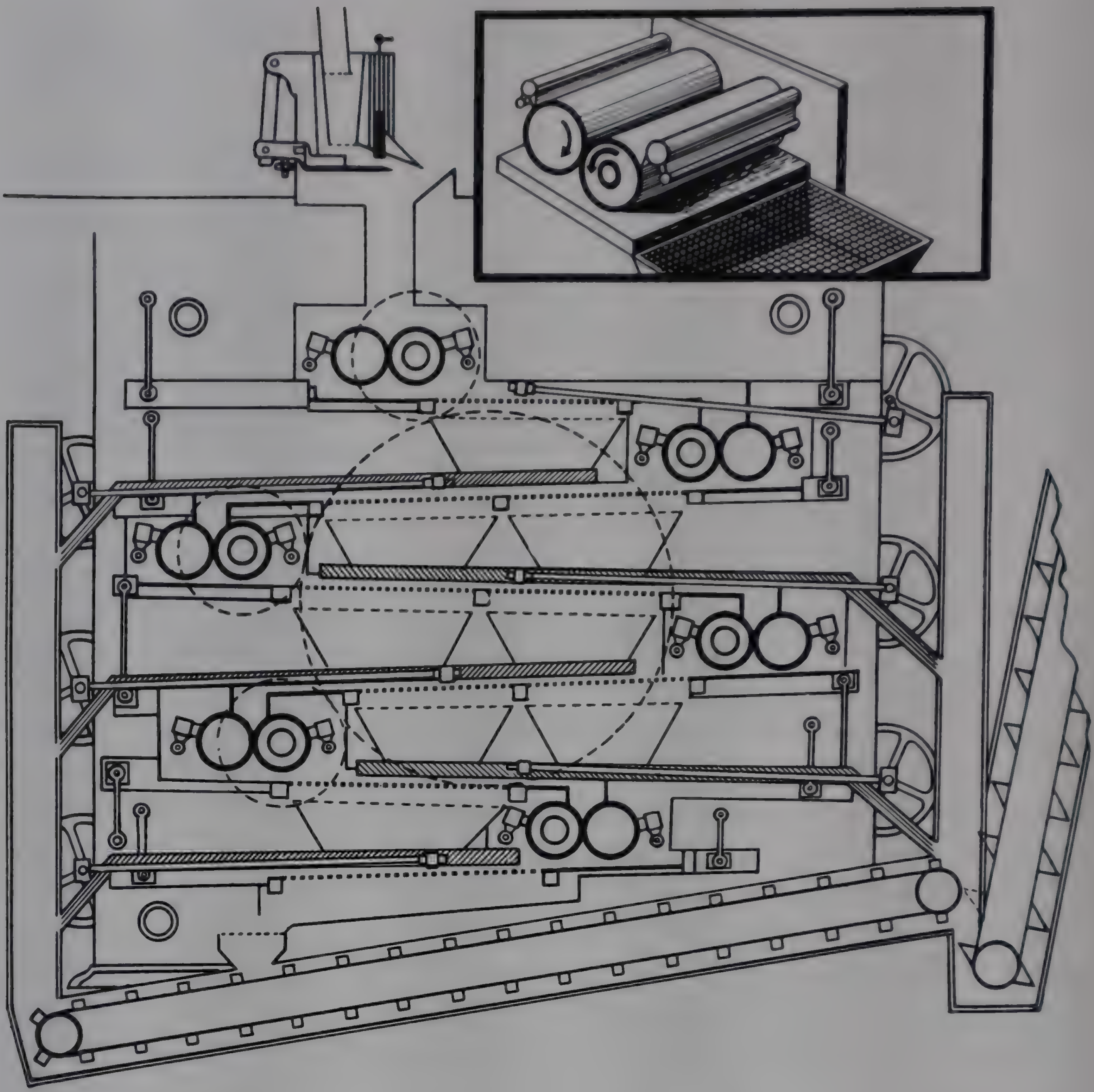


Figure 98. G. A. Buchholz's arrangement of six roller pairs, with vibrating sieves between each pair (1862). Three pairs of rollers were geared to a drive wheel at one end of the machine, as shown, while the other pairs were similarly driven from the opposite end. Though this machine was cumbersome, Buchholz was clearly aware of the need for making separations after each grinding operation. Stock fine enough to pass through the sieves was gathered by hoppers and carried to one or the other side of the machine, where it dropped onto a conveyer and was lifted to an upper floor for grading in reels.

description indicates that the old Sulzberger roller sets were still in use there, for grinding middlings only.

By 1869, however, no fewer than seven English, Scotch, and Irish mills had introduced a pregnant variation of the Sulzberger system, patented a full seven years before by G. A. Buchholz, who throughout his career was on the verge of great accomplishments. In his machine six pairs of rollers were used, set in a single frame and acting as a unit, though separated by vibrating sieves so that the larger particles of the chop from each break could be sent on to the next pair of rolls without the finer materials (Figure 98). Buchholz's rolls were 30 inches long and 10 inches in diameter, were corrugated, some of them with spiral grooving very similar to that used today, and they ran at differential speeds; but they were made of steel, which has not proved satisfactory for the purpose, and they were not flexibly mounted. Well-ground materials that dropped through the sieve under each pair of rolls were delivered to a long circular reel outside the machine so that the flour might be dusted out. The remaining materials were graded and reduced to flour, after the manner of Budapest milling, on four pairs of under-runner millstones set at different distances apart and making only 75 revolutions per minute.

Buchholz had here invented the "break" section of the modern roller mill and had placed it complete inside a single case, including even scalping sieves to release the finer part of the chop from further action by the break rolls. In addition he knew that he should grade his middlings and reduce them gradually, no less than the scalpings from his breaks. We are told that his system worked well enough to induce Radford & Sons of Liverpool to remove all millstones from their Albert Mill in 1870, the flour being made on slightly corrugated rollers from stock that had passed through Buchholz's machine. However, fatal weaknesses became apparent, and Buchholz's system passed into limbo. Too many parts of his machine were unadjustable and inaccessible for servicing or repair; it attempted too many things at once; and, even more important, since these difficulties might have been remedied, it did not have the support of an informed body of millworkers or of machines capable of handling the stock it produced, in particular the middlings. A lack of skilled operatives and of efficient purifiers, still not generally adopted in Europe at this time, was a fatal drawback.

The indifference and suspicion of the average English miller and mill operative toward innovation were attacked by a powerful and enthusiastic advocate of new methods when Oscar Oexle visited the country from 1868 on, at first on behalf of the Naeff roller mill. He obtained contracts to reconstruct a number of mills, introducing roller assemblies and Hungarian gravity purifiers, and in 1872–1873 superintended the installation of twenty sets of Naeff machines in the great Tradeston mill at Glasgow. Although he lost his sight in the dust explosion which destroyed that mill in 1872 – one of the first of the many that harassed large-scale millers during this transition period – he continued his profession as mill engineer, and only a short time later was influential in opening the way for rollers in the United States. There, also in 1872–1873, A. G. Mowbray of Winona, Minnesota, was experimenting with marble rolls manufactured by Edward P. Allis & Co., 20 inches in diameter and 48 inches long, set in sliding boxes adjusted by a screw and hand wheel. Mowbray's rolls were used to crush the wheat prior to grinding. The Allis firm also tried out cast-iron rolls, although it was not until 1875 that it could manufacture them round enough and hard enough to warrant their use. In March 1876 it advertised "rolls for crushing middlings and tailings."

In the early 1870's conditions in flour milling were ripe for something which would organize the mechanisms and processes that had grown up in widely separated locations into a soundly functioning system in general agreement with internationally accepted engineering standards. The very standards by which such a synthesis must be judged were themselves taking shape at that time. What are today commonplace engineering principles were just as unfamiliar, not many decades since, as the inventions that helped to clarify them. One can sense an entirely new logic of machine design in the 1887 complaint of an anonymous American writer in the *American Miller* that German machines often have "an iron mine and a lumber yard" included in their construction.

Because of this ferment of change and of ideas, a great deal was going to happen in a relatively short time wherever merchant milling was carried on, and it began about 1873. Before that date even large-scale milling in different regions was far from uniform. In the United States all mills of any size were automatic, the stock being operated on and transported by powered machinery. In Minnesota and at a few other locations, especially in the hard-spring-wheat area, the sieve purifier was in use; and pretty generally throughout the country the middlings problem was being attacked by way of higher and slower grinding, improved millstone dress, better bolting, and a dozen other tricks and artifices. In France, home of the best millstones and source of the central idea leading to the sieve purifier, millers were content to grind and sift and sell shrewdly as they had in the past. There were some, like Benoît, who had responded to Evans' radical inspiration, but for the most part France had become the country of small improvements and the *status quo*. It was otherwise in Budapest, where the modern system of gradual reduction had proliferated into a curiously luxuriant growth of man-served machines in which nearly 4,000 workers were needed to produce about 2,500,000 barrels of flour yer pear, or something like a mere 2 barrels per worker per day. Yet these mills had gravity purifiers in abundance, some of them were using Sulzberger or Naeff roller assemblies successfully, flours of the very highest quality were being manufactured, and a lively export trade reaching out to Austria, Germany, England, and even Brazil was rapidly growing.

Even in Hungary outside of Budapest, however, and in the rest of central Europe, including Russia, milling was carried on very much as it had been for generations. The United Kingdom, finally, was beginning to feel the pinch of diminishing home supplies of wheat, and with the increased use of imported flours was starting to cultivate a taste for better breads, in spite of the markedly inferior quality of her soft home-grown wheats. As she increasingly imported varieties of wheat drawn from all parts of the globe, varying in every characteristic, from degree of cleanliness to starch and moisture content, she began to take the lead in combining different wheats for milling and in the search for a method of processing that could be used on almost any wheat; but that very eclectic necessity for a time had the effect of retarding innovations in equipment. More recently, England has come to the fore in the design and introduction of mill machinery.

For all their regional differences of method and attitude, modern mills of large size everywhere were facing very much the same problems, varying principally in emphasis. Inside a large mill the noise was deafening, the heat in summer stifling, the persistent sweetish smell and taste cloying, the dust choking and dangerous to the miller's lungs, and in the event of an explosion to his very life. These advanced mills of the 70's were not only full of machinery, they were full of problems, inside and out. If it was an American mill, it was a maze of elevators, conveyers, spouts, and clattering apparatus, amid the inevitable dust and noise; if it was a Hungarian mill, it was a seeming confusion of hurrying men and flimsy machinery, and full of dust and noise; if it was an English mill, in addition to the dust and noise, there was much cruder machinery than in its American counterpart and less highly developed processes.

Because of all these difficulties the progressive millers of the 70's were reaching out not only for better processes but for raw materials and new markets and a better understanding of the part milling should play in a modern world. The American miller had answered the last question by committing himself to quantity production of essentially a single grade of flour, the best he could make. Long before Henry Ford had demonstrated in another field that the destiny of modern industry lay in serial production for a mass market, the millers of America had followed exactly the same path and with exactly the same results — a marked decrease in costs, along with a notable gain in quality, consequent upon a tremendous increase in the quantity of product manufactured.

This expanded volume created problems antecedent to the milling operations themselves. The New-Process Haxall mill at Richmond in the 70's ground more than 5,000 bushels, or more than three carloads, of wheat a day; the Washburn A mill at Minneapolis as erected in 1873–1874 used well over 4,000 bushels daily. In the course of a year these mills together ground the wheat grown on about 225,000 acres. To gather such prodigious quantities of grain and send it in a steady flow to single mills, a system of purchase and transport had to be evolved, with storage facilities at the source and at the mill. The Haxall mill had a wheat house with a storage capacity of 70,000 bushels. In less than a decade such figures would look small, but in learning to deal with quantities of this size, millers worked out methods for handling and preserving any conceivable greater amount.

As the millers' needs expanded, it became more important than before that farmers plant grain suitable for milling and baking. In wheats, yield and quality tend to vary inversely. The farmer has always been inclined to plant for a big yield, feeling confident that he'll make more profit on a large crop of passable wheat than on a smaller crop of premium grade. Millers therefore were greatly concerned with the dissemination of sound information, and good seed, among farmers. The appropriation of federal funds for agricultural schools in the Morrill Act of 1862 meant almost as much to American milling as to farming, and so did the founding of agricultural experiment stations from the 70's on.

New hard wheats were becoming available in the huge quantities needed by the modern mills, and to this fact most of the mechanical achievements of the last few generations in milling may be traced. The progressiveness of Budapest was in large part due to the difficulties and rewards of milling a hard winter wheat, especially the famous "steel" wheat of the Tisza River lowlands. Budapest was matched in this country by Minneapolis, again because of the hardness of its spring wheat. New methods introduced to deal with these wheats were only later adapted to others or made available for general use.

But large batches of wheat even of the same good quality are bound to differ in moisture and protein content, on account of local variations in growing conditions. In the effort to produce standard flours of known characteristics — a demand increasingly made on the miller by his customers — and as cost accounting was improved, it became necessary to mix wheats from different sources not only to lower costs and use available supplies but also to obtain a uniform material for grinding. It was thought far more economical to mix the wheats before grinding than to grind them separately and mix the flours; but it followed that they would have to be treated — tempered or conditioned, that is — to give them approximately uniform grinding characteristics. This problem was first of special concern to English millers, who gathered together the wheats of the world; but with the passing of time the advantage of conditioning became apparent to millers everywhere. In general, conditioning comes down to adding or subtracting moisture — risky processes both, unless they are carefully controlled — or to redistributing the moisture carried within the grain so as to dry the endosperm and toughen the bran. In the 70's in the United States wheat steamers were greatly favored for this purpose, although they are now seldom used here, since improved methods of conditioning have made the process unnecessary. It was at this time, too, that wheat-cleaning was greatly extended in an effort to remove every impurity before grinding.

After the flour was milled, it had to be packaged, distributed, and sold. The Washburn A mill turned out 300,000 barrels of flour a year, or about 1,000 barrels every working day. The barrel staves were cut out by machinery, but their assembly required 75 to 100 coopers. To whom could the sales department, certainly by then a necessary part of the milling organization, dispose of 200,000 pounds of flour a day? And whom could they persuade to take around 30 tons of feed every day, in face of the still very mild interest of American farmers in this product? To the need of more and better raw materials was added the need of new and bigger markets —which sent both American and Hungarian millers abroad to sell their output as eagerly as English millers went out to buy their supplies.

Between the assembling, cleaning, and conditioning of the wheat and the marketing of the flour, the old "grind and sift" of the ancient milling process went on. But here too by the 70's the old art was acquiring new outlines. It was recognized now as having three phases, calling for different techniques and different machines. First there came the breaking of the wheat grains, to produce middlings; then the reduction of middlings to flour; and lastly, whatever bran cleaning the mill might attempt. In between and in the midst of these processes the sifting proceeded, augmented by purifying with air currents. Sifting itself was greatly elaborated: the scalping off of large products was differentiated from the grading of products of intermediate size and the dusting or dressing of flour particles; complicated bolting arrangements were worked out; basic principles of effecting separations were clarified and became generally understood; and much progress was made toward embodying these principles in workable machines, especially in central Europe and the United States. An immense amount of ingenuity had gone into the development of air purifiers, as we have seen, and they had become the distinguishing feature of the New Process.

With the purifier invented and rapidly being perfected, the apparatus for grinding—the means used for breaking the wheat grain into its component parts—was the crux of the whole milling problem, and when it should be solved the milling art would move definitely into a new era of usefulness and success. The answer lay in perfecting roller grinding; the answer to that lay in the discovery of better materials from which to make rollers and in the improvement of their manufacture. When modern smooth rolls are brought into parallel contact with a strong light behind them, they are so perfectly round that no light leaks through. Another limiting factor was the need of a less rigid drive than metal shafts and gears. Though rope and belt drives had for long been understood in principle, their real use dates from the nineteenth century, and in the case of the former only from about 1856.

The synthesizing spark which in a surprisingly short time brought order out of the potentially fruitful confusion and variety of milling in the 70's was provided by Friedrich Wegmann of Wegmann, Bodmer & Co., Neapolitan millers. In 1873 he invented and in 1874 introduced into Budapest a roller assembly of markedly better construction than any that had previously been built, equipped with rollers made of a previously unused material, and so designed that one roller of each pair would be forced away from the other under sufficient pressure (Figure 97). His machine had two independently operating pairs of rollers standing on a horizontal line in a single case, with the inner rollers cross-geared so that they should need only one connection with the drive shaft. In Wegmann's original design the outer adjustable rollers rotated by friction contact with their inner nonadjustable mates, but by 1876 he was using spur gears to connect them. A gear drive has been followed ever since in most European roller mills, although until recently almost all American rollers were powered by belts. Wegmann's outer roller would swing away from the inner roller whenever something passing between the pair exerted sufficient pressure to overbalance weights applied against it by a system of levers. Weights were used so that the pressure on the ends of a roller could be equalized – rollers out of true would grind unevenly. In later mills designed by Wegmann and others, springs or elastic discs were used to hold the adjustable roller, although it is difficult even today to get two such elements whose action will invariably be equal.

Wegmann's original rollers were small – 4½ inches in diameter by 7 inches long – and made from 180 to 200 revolutions per minute. They were coated with unglazed porcelain, in the condition technically called biscuit, which gave them a dull, slightly roughened, highly abrasive surface, capable of taking hold of the stock, but somewhat too soft for long service – Wegmann's rollers would lose in diameter as much as 1/16 inch in six months. At first they were finely lined by diamond drills, but this only increased the wear. Although they could not be used successfully to break the wheat into middlings or to clean the bran at the tail of the mill, since they reduced it to a fine unremovable dust, Wegmann's rollers were the first fairly satisfactory substitute for the millstone in reducing purified middlings to flour. Even here they caked the stock so badly that it had to be "disintegrated" or "dismembrated" – pulverized, that is – between rapidly revolving discs before it could be bolted, the result being another line of machines added to the already full mill (Figure 92).

In Europe the use of rollers spread like wildfire in the larger mills under the impetus of Wegmann's invention. At an international exhibition of milling machinery held in Vienna in August 1875, ten different roller assemblies were shown. At Nuremberg the following year there were fifteen. One of the 1875 exhibits was manufactured by Ganz & Co. of Budapest, who were also making Wegmann's machine; it had rollers of chilled cast-iron. The Ganz firm had been using this material for many years to make wheels for railroad cars; they booked their first order for chilled-iron rollers for flour-grinding on August 22, 1874. The corrugations of the Ganz rolls were cut into the surface, not merely cast in – a great improvement. By early 1878 roller assemblies of one or another kind had displaced millstones in all the Budapest mills, except for the preliminary "ending" of the grain and the final cleaning of the bran, though these mills continued to be operated largely by hand labor. During the twelve years from 1874 to 1885 the Ganz firm sold 13,000 biscuit and chilled-iron assemblies themselves, mainly in central Europe, and in the twelve years following, 10,000 more; this was in addition to those marketed by firms in other countries which had been licensed to use their patents.

In the meantime things were also humming in America. In 1873, after a study of a large selection of French and German books and articles which Governor Washburn had secured through a brother who was Minister to France, George H. Christian had ordered a pair of steel rollers from a Minneapolis iron works. In late 1873, probably as a result of rumors of Wegmann's invention, a committee of Minneapolis millers, which included Charles A. Pillsbury and Christian, went to Europe to investigate French and Hungarian processes; they returned in 1874. On September 21, 1874, Christian (then in the employ of Governor Washburn) gave the Farrell foundry of Ansonia, Connecticut, an order for thirty-six pairs of smooth chilled cast-iron rollers, on the basis of what he had found out in Europe; they were tried in the Washburn A mill, but no regular use of the roller process was attempted at this time in any American mill.

The primary attraction of these early rollers was their economy. Dressing millstones was an expensive and time-consuming task, although until late in the 1890's they could still do a better job than rollers in flouring middlings and working up tailings. But as roller machines were improved, not only through harder and more uniform grinding surfaces and better bearings, but through perfecting the feed and the differentials at which the members of a pair were rotated, other advantages than economy also came to the fore. Corrugated chilled cast-iron was found to be an admirable material for breaking up the wheat to form middlings, while uncorrugated rollers of the same material with a dull (not actually smooth) finish proved excellent for reducing middlings to flour. For years, however, many preferred to use Wegmann's biscuit rollers for this purpose, although in time chilled-iron rollers were made that merely flattened the bran instead of powdering it as Wegmann's did. Almost simultaneously, about 1875, in this country and in England, R. L. Downton and Thomas Muir discovered that the germ could be flattened between smooth rolls and then scalped off, after the grain had been given a first breaking and scalping. This method of disposing of the germ is still used in American mills, although the English criticize it for pressing oil into the stock. They route stocks containing germ to rolls farther on in the system and use a special aspirator to blow the light material from the heavier germ particles.

In 1876 Oscar Oexle went to England on behalf of Wegmann's interests and by mid-1880 over 1,000 Wegmann assemblies had been sold there. In 1877 Oexle came to the United States on the invitation of Governor Washburn, and concluded an arrangement with Edward P. Allis & Co. whereby they became the distributors of Wegmann's rollers in this country. Previously, besides the Mowbray experiment with marble rolls, the Allis firm had made a few others of crude design, mostly of common cast-iron, which usually ran without differential and were used for germ-flattening. A set of such rolls had been shown at the Centennial Exhibition at Philadelphia in 1876. At first, after the agreement with Oexle, Allis imported the entire Wegmann machine; but by June 1878 they were importing only the biscuit shells and were placing them in a frame designed by W. D. Gray. The first installation of Gray's improved assemblies was in Kern's Milwaukee mill. Within ten years 25,000 pairs of rollers of all kinds located in Gray frames had been sold.

What Gray did to the roller machine can be taken as an example of what Americans were to do over and over again to other machines in many fields of manufacture. In his own words: "I had faith that they would become generally used if they could be put in better shape; that is, if they could be mounted in a frame with the proper adjustments and drive, where the wear and tear would not be so great, and where the miller could control them so that they would be less noisy, and have a larger capacity. . . . In the Wegmann machine the frame was light and flimsy, with nothing rigid about it. I constructed my frame of one solid casting, so that there could be no rack, or tremble, in it. The stationary roll was held rigidly in place. . . . I decided, also, that a belt was needed to do away with the train of spur wheels on the Wegmann machine."

These were not trivial changes, although such Americanizations of foreign machinery have often been misunderstood as mere imitation by those who focus attention exclusively on the "principle of operation" of a machine. They indicated a very different attitude toward machinery from that common at the time in Europe. Gray viewed Wegmann's roller machine not merely as performing a certain specific function — that of reducing middlings to flour — but also as a potential agency of mass production. He realized that a machine or process can be fully useful only if it is able to handle enormous quantities of raw material successfully, without undue wear or expense or loss of effectiveness, and also if it can itself be manufactured by quantity-production methods. The pressure of these characteristically American demands on machine design has been extraordinarily fruitful; by now they are elementary commonplaces of good engineering, although they are easier to state than to realize in practice.

Because of their sturdier mounting and belt drive, Gray's rollers could be driven at higher speeds than gear-run rollers, up to 500 or more revolutions per minute for the fast roll, as compared with about 350 revolutions for English machines; the grind per inch of roll surface was thereby increased. The usual differential for break rolls is about 2½ to 1. The English still criticize our belt-run roller sets for slippage, which if it occurred would affect the grind by changing the differential; but with well constructed, properly run machines belt slippage becomes negligible. We still criticize their gear-run machines for noise and the backlash due to imperfectly constructed or worn gears, which also could affect the grind adversely. It is true that improved gear types have minimized these difficulties — noiseless helical gears were available from 1877. As English rolls wear down, however, the gears must eventually be replaced by others of smaller diameter; the center lines of the rollers must be brought closer together to maintain the original distance between roll surfaces. This adjustment can be made on American machines by relocating the idler pulley around which the driving belt runs, after the adjustable roller has been reset.

Rollers gave the miller far greater control over grinding than had been possible with millstones, and this advantage was increased by two improvements: first, feed devices which spread the stock evenly in time and space into the nip of the rolls, and second, means of setting the rollers so accurately that they could be counted on to maintain a precise spacing between them. This last replaced the earlier method of mounting them in contact and depending on the stock to push them apart. With corrugated, non-touching rollers running at different speeds, the grinding action is less a shearing than a twisting of the grain on itself, with the corrugations tending to hold the particles fast while their contents are opened up and spread out. The control became so fine that the grains could be run through one or two breaks without producing more than 3 or 4 per cent of flour — a good thing, since break flour is necessarily mixed with bran and at least a little dirt — or so that scratch rolls could go a long way toward scraping the softer endosperm off small bits of tough bran, without breaking the bran and indeed while flattening it for easier bolting. Rolls could be set to arrange a gradual series of breaks or reductions, to flatten the germ as well as the bran, to break semolina or sizings (large middlings) into smaller particles; they could even be set quite far apart to give the grains a mere cleaning touch prior to the first actual break (the so-called *Hochschrot* of the Hungarians, comparable to the "ending" action of millstones set high on a stiff rynd). The very versatility of the roller process raised problems farther on in the mill, especially in the bolting section, as we shall see.

Almost from the first introduction of Wegmann's rollers, and certainly after the Ganz improvements, millers found that they could produce a larger proportion of better-grade flours in the new way, although no greater total extractions were obtained with rollers than with millstones so long as the quality of the best flours was maintained; under normal conditions about one quarter of the grind still went into the feed bin or was lost in the mill. The following Hungarian comparisons, quoted by Oexle in an article which appeared in early 1876, are typical of the period in the general results obtained:

	Millstones	*Rollers*
Best flours (Grades 0 to 3)	24%	34%
Intermediate flours (Grades 4 and 5)	11	22
Poorest flours (Grades 6 to 9)	41	20
Total extraction	76%	76%

In experiments made in 1873–1874, using only Wegmann's porcelain rollers along with millstones, 28 per cent of superior flours were obtained, 15 per cent of intermediate grades, and 32 per cent of the poorest flours – a sufficient improvement over simple millstone extractions to warrant the shift to Wegmann's machines and, taken in conjunction with the above figures, a striking indication of the progress then possible within a year or two.

Hungarian flours of Grade 3 were generally considered equal to our patent flours; since those of Grades 6 to 9 were poorer than could have been sold in the United States, a mixture of Grades 0 to 5 can be taken as corresponding to American straight flours of the time. It will be noted from Oexle's figures that only half as much of the poorest flours was produced with rollers as with millstones alone, and that, whereas only about one third of the millstone product was of patent quality, nearly one half of the roller flour reached that level. Even as early as 1881, the following extractions were cited by Abernathey as typical of good American mills:

	New-Process Milling	*Gradual Reduction with Rollers*
Patent flour	30%	45%
"Bakers" flour (intermediate)	30	15
Low-grade flour	15	15
Total extraction	75%	75%

Abernathey pointed out that the increase in patent flour with rollers was in part obtained at the expense of the lowest quality, which was downgraded somewhat by the innovation. While we need not draw dogmatic conclusions from a comparison of Oexle's and Abernathey's figures, the roller process as practiced in this country had plainly undergone considerable improvement by 1881; 80 per cent of the total flour produced was said to be of patent and intermediate grades, as compared with about 50 per cent on the basis of the Hungarian figures, and this had been achieved by decreasing the percentage of low-grade flour. Abernathey's figures seem the more credible in that the results of New-Process milling stand roughly intermediate between those obtained with millstones and with rollers. We know that New-Process millers produced considerably more patent flour than previously, but only at the expense of making a disproportionate amount of not easily salable low-grade flours. To keep their poorer flours at a salable level of quality, American millers under both the New Process and for a time after rollers were introduced sometimes had to limit their patent flours to as little as 25 per cent of the wheat ground – a figure close to that cited by Oexle for Hungarian millstone extractions. As Chisholm pointed out in 1882: "It was here that the New Process was found to be inherently weak. It could in no way reconcile a close yield with a good percentage of 'patent.' The growing public taste demanded a good article of wheat flour, and to produce this the miller was obliged to sacrifice a portion of his percentage of patent."

It was by following the line of quality, with its possibility of high rewards if the entire grist could be marketed, that New-Process millers with their carefully adjusted millstones and purifiers were induced, sometimes reluctantly, to seek at least some method of supplementing the ordinary millstone, if indeed it was not to be replaced entirely. Thus they began to make their first experiments with roller milling and the modern gradual-reduction system. We must not make the mistake of judging them from our position at this end of the time scale – we know that roller milling was going to win out; they didn't. Besides the many varieties of roller machines, ardently advertised with all the paraphernalia of exaggeration, "humor," and testimonial so characteristic of the period, there were any number of other devices clamoring for a place in the mill – fancy-dress millstones, under-runner millstones, "decorticators," "dismembrators," Jonathan Mills' "degerminator," Louis Gathmann's very similar "reduction machine," even breast mills similar to that illustrated by Böckler in 1662 and cone machines like Ramelli's (Figures 54 and 92).

Supposing the puzzled miller were to choose rollers, and those of good manufacture at that, the cost of even a few assemblies was very considerable. But the expense did not stop there. Abernathey writing in 1881 says: "Where is there a mill today that the simple introduction of rollers or other reduction machines would benefit very largely? In order to be useful, the Gradual Reduction machines must be flanked and supported in the center by numberless reels, purifiers, aspirators and all other contrivances for separating and dressing the flour after it leaves the machines. Such an array of reels, purifiers, etc., that is required for a 200-barrel Gradual Reduction mill would startle an ordinary mill man out of his boots."

As Abernathey here suggests, roller milling was much better adapted to large enterprises than to small, not only because of the demands it laid on capital but because the production needs of a roller mill in raw materials and in markets were all but insatiable. It was not everywhere that mills of moderately large size could be erected, in view of market and transportation limitations, nor was every miller competent to manage a large enterprise. Just as engineers were increasingly needed to build flour mills, so people with a managerial bent were increasingly required to run them. Between the two the old-style all-around miller was pushed into a subordinate position, and from even these narrow confines he was eventually to be evicted by an increase in the need, on the one hand, for minor mill technicians of an entirely new stamp and, on the other, for almost untrained millworkers.

on the capital required for the operation." American millers would be the first to act on and prove this sound economic truth.

Naturally, the priority of Minneapolis in the synthesis of modern milling has been disputed by isolated examples elsewhere. There is the assertion by the almost contemporary English authority Voller that Oexle equipped an all-roller mill in Budapest in 1869, but Oexle himself wrote in 1880 that only one Budapest mill — the original Walzmühle — carried the roller process even up to the last stages of grinding, which even in that mill was effected by millstones. Oexle, in fact, never was convinced that rollers would entirely replace millstones, although after introducing Wegmann's porcelain roller assembly to England and later to America, he had a prominent part in effecting the change-over in Minneapolis. The necessity of dispensing with millstones entirely would become apparent only where rollers were tried for special purposes in an already automatic plant, such as for many years existed nowhere in Europe. According to *Die Mühle* the great European milling center of Budapest had no mill without millstones as late as 1882, and probably much later; and no mill there was automatic until long after that date.

England presents stronger but still insufficient claims. There was the Albert Mill of Radford and Sons, Liverpool, where G. A. Buchholz's six-break-in-one-machine was installed in 1868 (Figure 98). Two years later at this mill, although apparently not at other Buchholz mills, "the stones were entirely removed, slightly grooved rolls being substituted" for the later processes. But still this mill was not fully committed to gradual reduction; the six pairs of rollers were used as one rather than to accomplish successive stages of a serial process, and their product was mixed. In many other early roller mills the products of some or all of the intermediate breaks were similarly mixed, in large part nullifying the effect of using a number of breaks and missing the chief benefit of gradual reduction. Buchholz's inefficient and inconvenient system soon passed out of use.

It is possible that Francis Stallmaier set up the world's first automatic gradual-reduction mill when he remodeled the plant of Will Thompson & Son in Wakefield, England, in 1873, but he used millstones as well as rollers. The 1879 mill of Barlow & Sons of Bilston, planned by J. A. A. Buchholz, son of the first Buchholz, and often called the first automatic roller mill, fell short of the standards of gradual reduction since it used a low-grind system in a single machine containing three grooved rollers, set one between the other two to form two pairs. The wheat was severely crushed under as much as six tons' pressure between the first pair of rolls; after sieving the chop was carried to the second pair, where the grinding was completed.

Henry Simon also began his notable roller-milling career with a sudden-death system — that espoused by Nagel & Kaemp of Hamburg. The wheat was fractured between smooth chilled-iron rolls running without differential, and was then sent to a "dismembrator" similar to the machines of Figure 92. Simon tried out this system in 1877 in the McDougall Brothers' mill at Manchester, and on August 16, 1878, signed a contract with them for an experimental all-roller gradual-reduction mill, completed in mid-1879, in which he used the Daverio roller assembly which had just made its appearance in Switzerland. In this assembly three rolls were arranged in line to form two independently acting pairs able to handle totally different stocks by virtue of an ingenious cross-feeding arrangement.

Figure 99 shows Simon's plan for his mill. Such a chart, now called a flow sheet, indicates only how the stock divides as it passes through the

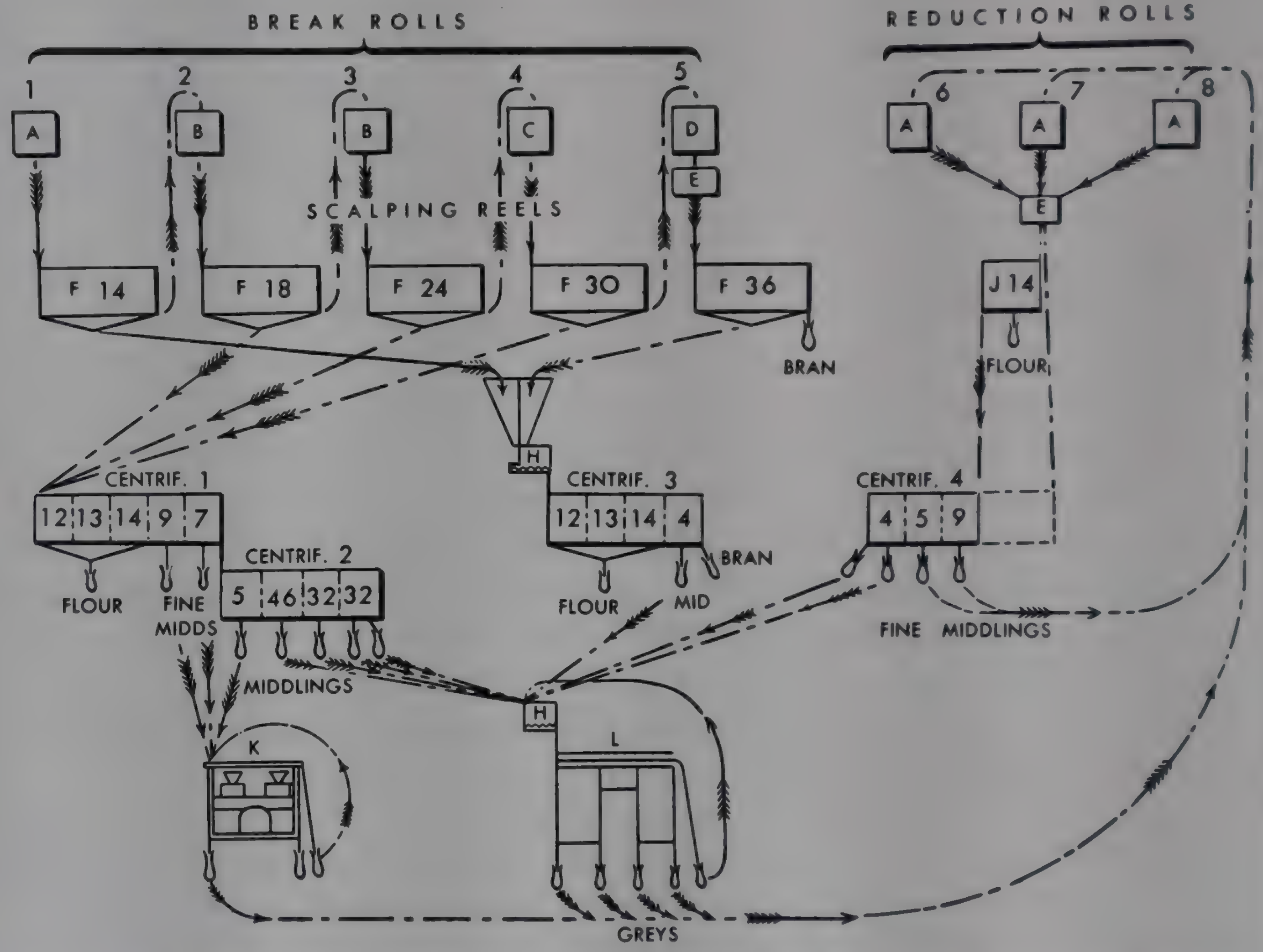

BREAK ROLLS
REDUCTION ROLLS
1
2
3
4
5
6
7
8
A
B
B
C
D
E
A
A
A
E
SCALPING REELS
F 14
F 18
F 24
F 30
F 36
BRAN
J 14
FLOUR
H
CENTRIF. 1
12 13 14 9 7
CENTRIF. 3
12 13 14 4
CENTRIF. 4
4 5 9
FLOUR
FINE MIDDS
CENTRIF. 2
5 46 32 32
FLOUR
MID
BRAN
FINE MIDDLINGS
MIDDLINGS
H
K
L
GREYS

Figure 99. Flow sheet of Henry Simon's first complete all-roller mill, using the Daverio assembly, which was in operation at the McDougall Brothers' mill, Manchester, England, in 1879. This mill was not completely automatic, and made liberal use of returns, as the diagram shows. The letters on the boxes representing the machines are those of the original drawing, which we have followed closely: K and L are purifiers; E, probably "effective" purifiers (simple aspirators); H, hoppers with conveyers to mix the stocks placed in them; J, a flour reel to which the stock was sent for flouring when the miller considered it ready. The numbers on the reels indicate the meshes of the sifting material; those on the scalping reels give the number of strands to the inch, while the smaller numbers on the centrifugal reels were based on a different scale. Flour was bolted on cloths of about the same mesh as today.

mill, and the sequence of machines through which each portion of stock travels. In order to present the bare logic of a milling method, a flow sheet may leave out a great deal – what the machines look like, how they operate, where they are located, how many of them are assigned to each function, how the stock is carried from machine to machine, and accessory processes like dust collection and the gathering together of similar end products. The logic of Simon's flow sheet is so unadorned that not everything in it is clear at this remote date, but the main outlines are obvious. It is apparent that the mill was not entirely automatic, that it contained too few gradations of reduction surface in proportion to the number of breaks, that unlike stocks were mixed, and that the unwise policy of returns was liberally followed; but we nevertheless here have the beginning of important things for English milling. Although J. Harrison Carter preceded Simon by one year in building the first English *automatic* roller mill, for John Mooney in 1880, Simon for many years was a leader in the propaganda for English roller mills, and in their construction. He and the few like Carter who also felt the need of a change were but little heeded until events across the Atlantic gave weight to their words. In the early 80's there was a greater diversity of roller milling ideas in England than at any place in the United States, although there was less decisive action throughout the entire United Kingdom than in our Northwest alone.

Curiously enough, the first American all-roller, gradual-reduction mill was also based on the relatively little used Daverio roller assembly. Six of these machines, capable of twelve graded grindings, had been on display at the Philadelphia Centennial Exposition of 1876, along with purifiers and reels for a complete mill. At the close of the Exposition these machines were bought by John and William Sellers and installed in their nearby mill, together with several additional roller assemblies directly imported from Switzerland. William de la Barre, soon to become an important figure in Minneapolis milling, saw them in operation without millstones in the summer of 1877. This mill was almost certainly automatic; it was situated on the Wissahickon, where Evans' ideas had been acclimated for almost a century and, being a business venture owned by well-known industrialists, was evidently no small affair. But, quoting de la Barre, it did not employ "anywhere near the Hungarian or gradual reduction system of milling," and in any event this and other mills along the Wissahickon soon passed out of use and were torn down when Philadelphia's Fairmount Park was extended. There remains almost no record of the Sellers' mill, and it seems to have had no effect on American milling except as it may have influenced the young de la Barre. To use a sociological phrase, the Sellers' mill did not succeed in institutionalizing the idea it embodied; and that, of course, is far more important historically than mere priority in time.

In the case of a synthetic creation like the automatic, all-roller, gradual-reduction mill, the important historical fact is not who first set one up, but who first organized one so that others were induced to follow his example, and were able to do so; in other words, when and by whom was a decisive trend originated? In this sense, it was Wegmann, along with the Ganz people, who deserves chief credit for the roller-mill idea, rather than Sulzberger and other predecessors. In this sense also, it must be recognized that modern milling was initiated in the Washburn experimental mill of 1878–1879, as planned by Oscar Oexle and executed by W. D. Gray for E. P. Allis & Co. under the driving aegis of C. C. Washburn, and as soon thereafter revised at the suggestion of William de la Barre to include chilled-iron rollers.

It is a significant fact, and one typical of the period being ushered in, that no single person could rightfully claim more than a small share of the credit for this achievement. Close behind Washburn, Oexle, Gray, and de la Barre, and pressing them for recognition, were many others: U. H. Odell, who was in direct charge of the installation of the machinery; the miller F. Wohlgenannt, who was imported from Hungary to run the mill and was useful whenever overseas wisdom could be applied – which, of course, was not as often as he thought; the various adapters and perfecters of the French sieve purifier, each certain that his particular contribution was decisive; the staff of the Allis works, then rapidly forging ahead to an enviable position in the new profession of mill engineering as contrasted with the old millwrighting and mill-building; the rank and file of millers in Minneapolis, in eager quest to learn any new thing about their art, then in transition toward becoming almost, though never quite, an applied science; and behind all these the Europeans who had given the first impetus which was here being brought to fruition. Modern technological advance is democratic in a double sense: while depending on teamwork, it also gives the individual more scope for effective action. While having little use for the merely individualistic, it directs and develops the capacities of those who have learned to participate in its group activities.

It can be said that the Washburn experimental mill of 1878–1879 came into existence through a series of accidents, but these accidents could not have occurred, or have had the same combined outcome, at any other time or place. The time was ripe for synthesizing many existing ideas, and the terrible explosion of 1878 was the first of the chain of happenings that made the experimental mill possible.

The foundations were being laid for an addition to the Washburn B mill when the A mill exploded on May 2, 1878. On arriving at the scene, the Governor, with characteristic decisiveness, paced off a number of additional steps from these foundations and gave the order, "Build out to that point." The result was a somewhat oversized building 145 feet long, which was not called the C mill until January 1880, after it had been running for a full year. It is probable that Governor Washburn had intended to have the B-mill addition planned by Adolf Fischer, a Budapest milling engineer whom he had met abroad in 1877; but the explosion made the need for more capacity so urgent that the extension was rushed to completion by E. P. Allis & Co., while Fischer was instructed to make plans for a new A mill. The finished addition was far larger than the old B mill, containing 30 run of stone as compared with the old 12, and in addition 22 pairs of Ganz chilled-iron rollers, supplied by the Allis people, of which 6 were for wheat breaking and 16 for reducing middlings. The mill had 44 sieve purifiers, 75 reels, and 47 dust houses measuring 8 by about 7 feet in cross section — standing in a row they would have extended 329 feet. By 1882 this C mill had a capacity of 2,000 barrels a day.

The greatest innovation of the C mill was the installation of the Brehmer-Behrns dust exhaust on all the millstones (Figure 93). Greatly concerned by the 1878 disaster, and hearing of the exhaust, Governor Washburn had telegraphed the Brehmer brothers in Philadelphia to come to Minneapolis to demonstrate the device. They found a representative in young William de la Barre, an engineering friend only casually acquainted with milling. When he arrived at Minneapolis, the Governor insisted that a number of machines be obtained for trial, but would assume no financial risk. On learning that the Brehmer brothers would not ship the machines until they were paid for, de la Barre quietly used his own small savings to get them to Minneapolis, where they proved entirely satisfactory. After the Governor was told what had happened, he ordered exhausts for all his millstones, gave de la Barre a commission on the sale, and offered him a position as his engineering adviser. When de la Barre answered that he knew little about milling, the Governor replied, "No one knows where this thing will lead. We will grow up in it together." Thus began the young man's increasingly important connection with the great changes then beginning to take place.

Because of the length and number of the Governor's strides in pacing off the dimensions of the new mill, there was a vacant space 18 feet deep across its entire south end. W. D. Gray, the Allis engineer in charge of the work, in reminiscences written twenty years after the event, says: "I had had my eye on the vacant space in front of the Washburn mill for some time, and thought it would be a good place to test the full roller process; and knowing the tendency of C. C. Washburn for push and that he was always very liberal in this direction . . . I suggested that he allow me to place in the vacant space a small experimental roller mill of about 100 barrels capacity [per day]."

The Governor agreed, and arrangements were shortly thereafter completed for Oscar Oexle to come to Minneapolis with rollers, gravity purifiers, reels, and ideas for the project. Oexle brought with him the

Wegmann porcelain rolls in which he was then so deeply interested, and laid out a plan for the mill to be constructed by the Allis firm through the top four floors in the vacant space at the end of the new building. Though Gray left for Europe before work on the experimental mill was advanced, and returned about May 1, 1879, only a short time before it began operation, at the latest by June, the mill plan was a synthesis of his own and Oexle's experience, since it contained not only roller assemblies and gravity purifiers, including aspirators, but also sieve purifiers, and was laid out on well-tried American automatic principles. It was Gray who persuaded Governor Washburn to have half the roller assemblies driven by belts, instead of by gears as was the custom abroad; after trial the belt method proved superior and became the standard for American mills.

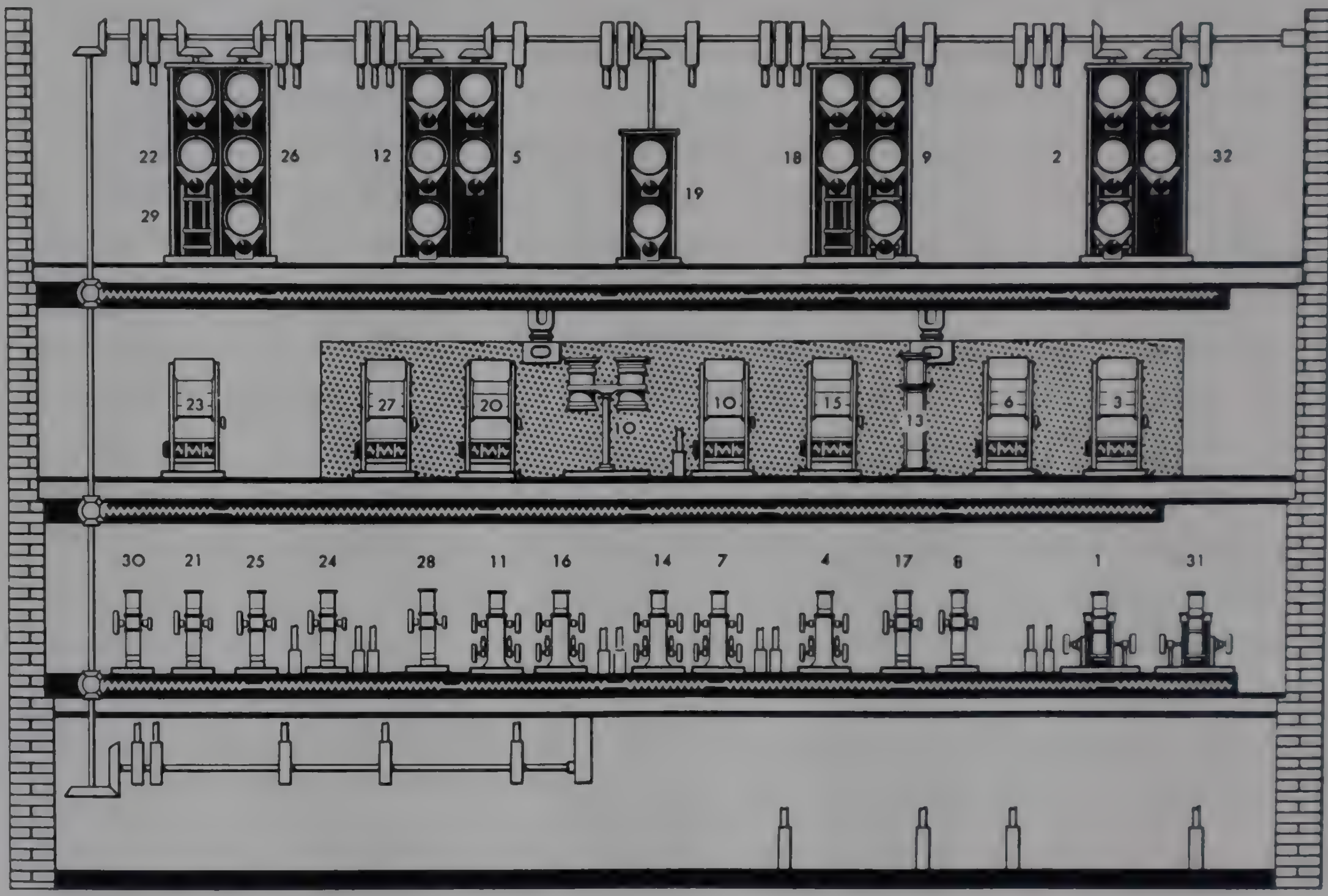


Figure 100. Washburn automatic, all-roller, gradual-reduction mill as set in operation in what was later called the C mill, about June 1879. All extraneous matter has been left out of the drawing, including partitions, elevators, some shafting, and shafting supports. On the lowest machine floor stood the four break-roller assemblies (1, 8, 17, 31) and the ten reduction assemblies; on the intermediate floor, the purifiers; on the top floor, the bolting chests with their round reels and aspirators (*e.g.*, 29). The machines are numbered to correspond to the flow sheet of Figure 101, two pages beyond. All the purifiers except two were American sieve machines; these (13 and 10, the latter used in conjunction with the sieve machine to its right), were Haggenmacher gravity purifiers. Of the roller assemblies, 1, 4, 7, 11, 14, 16, and 31 were belt-run; the remainder were gear-paired. Though this mill is called experimental, it produced flour until 1899, when it was torn out to make room for an enlarged mill then being installed.

As shown in the original floor plan, which we have clarified somewhat in Figure 100, the Washburn experimental mill was completely automatic, used no millstones, was organized according to gradual-reduction principles – and thus first conforms to the definition of modern milling. It received wheat from the cleaning section of the C mill, and sent its finished products to the packing section of that mill. For the four breaks of the experimental mill porcelain rolls whose surfaces were diamond-grooved were used at first. The capacity of the experimental mill proved to be low, although quality was high and yield satisfactory, and at Gray's suggestion the porcelain break rolls were replaced soon by four pairs of Ganz corrugated chilled-iron rolls which Governor Washburn had purchased out of curiosity in 1878, but which had remained boxed until they were put into the experimental mill. In de la Barre's judgment, these were the first such rolls to be used on breaks in this country. Porcelain rolls were used for some time for the ten middlings-reductions, although they were replaced, probably in 1880, by Ganz rolls.

The Washburn experimental mill was so important that we have worked out the flow diagram of Figure 101 from the original drawing on which Figure 100 is based. After each of the four breaks the chop was sent to a separate set of reels for scalping, grading, and dressing. These reels were unusual for American mills in that they were only 10 feet long. The tail stocks of the reels for the first three breaks were also aspirated. Fine stock from the reels for the first two breaks passed to special dressing reels, the tailings of which underwent purification, reduction, and further bolting at the end of the mill. This represented a considerable extension of American practice, in line with Hungarian ideas, and yielded only low-grade materials. The main stock from the first break was treated for the most part according to well-accepted principles, producing patent flour, although the tailings of the patent reels were extensively retreated, also on Hungarian lines. The main body of the stock, from the second and third breaks, was given a merry run-around through sieve and gravity purifiers, reduction rolls, and reels to produce the bulk of the patent flour. At one or two places, as shown in the chart, the weak policy of returns was followed, and at other places stocks of different character were combined; but the complexity and organic maturity of the Washburn experimental mill are strikingly apparent when it is compared with the English Simon experimental mill of the same year (Figure 99). Its chief feature, of course, was the multiplicity of reductions – ten in all – following on the four breaks, leading inevitably to a complex interweaving of bolting and purification operations to accommodate the many varieties of stock produced in the mill.

All Minneapolis was agog over the experimental mill. The town was filled with rumors, since for a time the doors of the mill were closed to the public. There was active speculation as to what would happen in the A

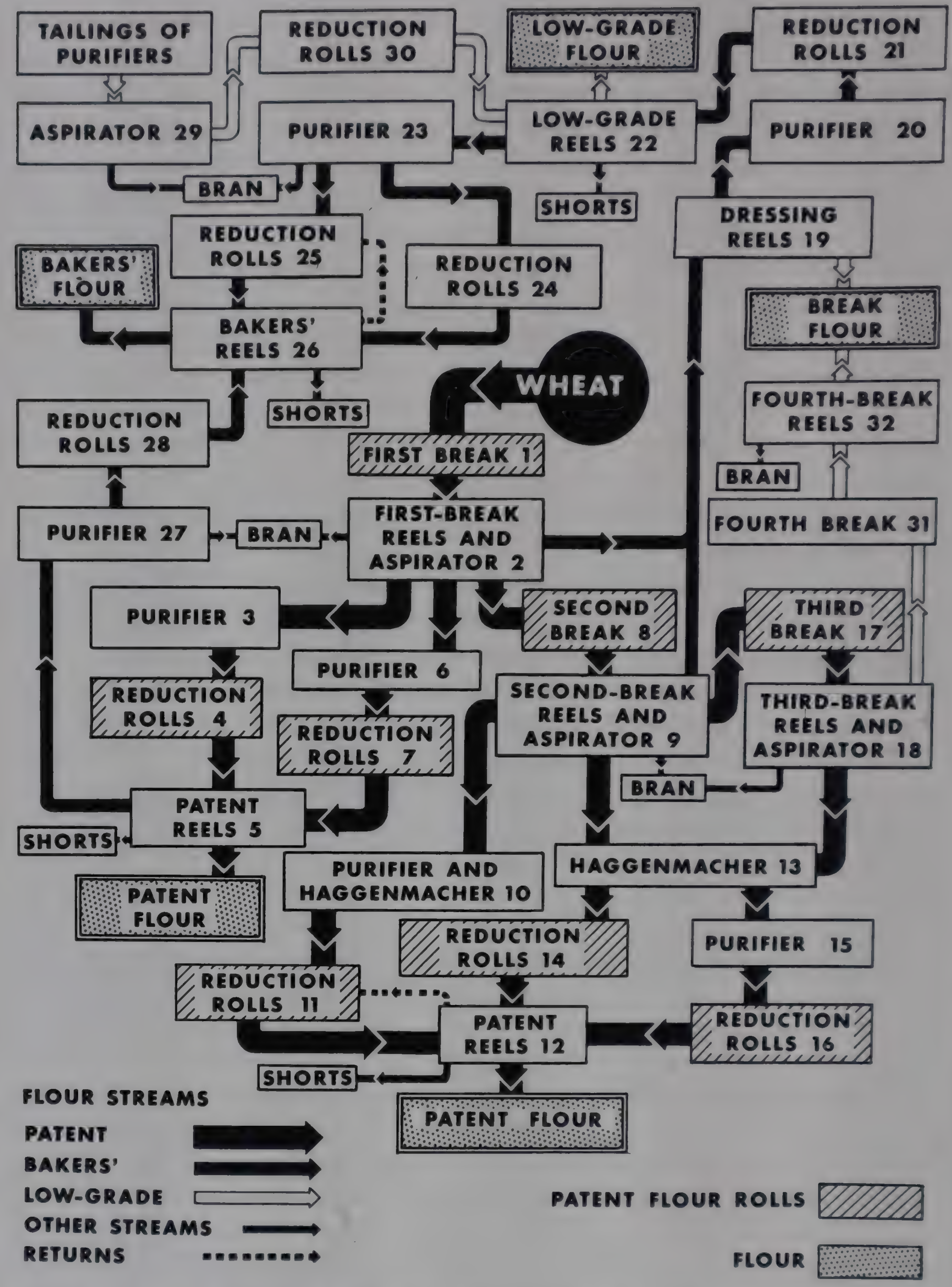

TAILINGS OF PURIFIERS
REDUCTION ROLLS 30
LOW-GRADE FLOUR
REDUCTION ROLLS 21
ASPIRATOR 29
PURIFIER 23
LOW-GRADE REELS 22
PURIFIER 20
BRAN
SHORTS
DRESSING REELS 19
REDUCTION ROLLS 25
BAKERS' FLOUR
REDUCTION ROLLS 24
BREAK FLOUR
BAKERS' REELS 26
WHEAT
SHORTS
FOURTH-BREAK REELS 32
REDUCTION ROLLS 28
FIRST BREAK 1
BRAN
PURIFIER 27
BRAN
FIRST-BREAK REELS AND ASPIRATOR 2
FOURTH BREAK 31
PURIFIER 3
SECOND BREAK 8
THIRD BREAK 17
PURIFIER 6
REDUCTION ROLLS 4
REDUCTION ROLLS 7
SECOND-BREAK REELS AND ASPIRATOR 9
THIRD-BREAK REELS AND ASPIRATOR 18
BRAN
PATENT REELS 5
SHORTS
PURIFIER AND HAGGENMACHER 10
HAGGENMACHER 13
PATENT FLOUR
REDUCTION ROLLS 14
PURIFIER 15
REDUCTION ROLLS 11
PATENT REELS 12
REDUCTION ROLLS 16
SHORTS
PATENT FLOUR
FLOUR STREAMS
PATENT
BAKERS'
LOW-GRADE
OTHER STREAMS
RETURNS
PATENT FLOUR ROLLS
FLOUR

Figure 101. Flow diagram of Washburn experimental mill. The numbers correspond to the machines in the floor diagram of Figure 100, page 248. As indicated at the upper left corner, the tailings of all purifiers were treated along with other stocks to make low-grade flour.

mill, whose walls were rising from its ashes in late 1879. The following note from the *American Miller* is typical: "The Washburn A has its eighth and last story with the observatory nearly completed; but on what system it will make flour – whether Hungarian, roller, or with the millstone – remains to be decided after the elaborate and extensive experiments now in progress in the Washburn B have been concluded." By "Hungarian" was meant, of course, gradual reduction with a mixed system of rollers and stones. While, as Gray says of the experimental mill, "the success was so great that Mr. Washburn at once took steps to introduce rolls into all his mills," beginning with a remodeling of the B mill, it was the mixed system that gained the ascendency.

At this time, in late 1879 and early 1880, Hungarian ideas reached their greatest popularity in Minneapolis. Wohlgenannt was placed in charge of the changes in the B mill and on their completion was moved over to the A mill, by then ready for machinery. Set up as a 1,000-barrel mill, the B used a much more elaborate system than the experimental mill, on account of its size and because it was far more "Hungarian." In addition to retaining millstones, some of the many grades of middlings that were manufactured were actually caught in bags and carried to the next stage of reduction, which varied according to the judgment of the miller; it was on this account that the B was called "the bag mill."

Even as late as 1890 the mills of Budapest required about 4,000 men to produce a considerably smaller quantity of flour than was turned out at Minneapolis by less than 1,500 workers. Twenty-five years earlier, however, the Budapest mills had used almost as many workers as in 1890 to produce less than half as much flour, so that even there mechanization was going forward. Until its Hungarian characteristics were eliminated or Americanized, the B mill was little liked by the rank and file of millers, and it was held to be a form of punishment to be transferred to it.

By early 1880, when Governor Washburn decided to fit the western half of the A mill with machinery, the Hungarian craze had already slightly abated. One of the things that gave pause was Fischer's plans; they had arrived, and called for an unconscionable amount of hand labor, the manufacture of eight grades of flour, and the importation of a millful of expensive machinery from abroad. His ideas were so impractical that they caused a reaction, and the west side of the A mill as completed in mid-1880 was less Hungarian than the B mill, although, being larger – 1,700 barrels as compared to 1,000 – it contained much more apparatus. The western half of the A mill had ending stones and 10 run of French burrs, in addition to 86 roller pairs – 74 of chilled iron and 12 of porcelain. It used 78 purifiers, 16 aspirators, 148 reels, and 16 graders – flat sieves of which at least some were 40 feet long and 20 inches wide. It had 38 sections of Washburn patent dust rooms (Figure 95).

This mill was less automatic than the experimental mill – some stock was taken across the mill in man-propelled carriages, to avoid attrition – but more definitely given over to gradual reduction. The year 1880 was a watershed; at that moment no practical miller anywhere could see his way to building a really large mill on an all-roller basis: the technical problems at the tail of the mill were still too complex, the financial risk too great. It can be seen how stocks were treated aimlessly – without predetermination – toward the tail of the Simon experimental mill, and how they were given a run-around at that point in even the more highly developed Washburn experiment. As ever better middlings were manufactured and reduced by ever increasing batteries of purifiers and rollers, the former middlings problem was transformed into the problem of bolting the reduced stocks cheaply and efficiently on the one hand, and of treating the richer brans that were being produced at the tail of the mill on the other – of removing what flour remained on the bran and, especially in America, of finding a market for the bran that was left. In the first flush of New-Process days in the Northwest, the profits rolled in for any who could make a patent flour, no matter how inefficiently. The scramble to manufacture patent flour was followed by a mad scramble of mill building, which was at its height in 1883, and which was soon accompanied by another for markets and for more economical milling methods. At the start roller milling did more to aggravate these problems than to solve them, although the key to larger markets and cheaper flour was to be found in that invention.

For all its Hungarian quirks, which would soon be ironed out, the western half of the Washburn A mill was far in the lead of American milling, as becomes evident when it is considered in relation to the displays at the Cincinnati Milling Exposition of June 1880, simultaneously with its opening. There were 170 exhibitors, including 14 from Europe. Although purifiers of 22 makes were shown, only two roller manufacturers had exhibits – E. P. Allis & Co., who had a large display with some machines running, and the Downton Manufacturing Co. Six completely equipped small running mills were set up, of which only one went beyond the New Process – a Jonathan Mills' gradual-reduction mill using five of his disc machines (metal millstones set vertically) followed by his bran duster. In all the running mills, only a single roller assembly was used, by Nordyke & Marmon, to flatten the germ. An English visitor estimated that nearly two and a half times as much machinery was required in a well-equipped mill as by old methods, even though no rollers were used, but that the miller's profit was doubled through the resulting improvement of the product, in spite of the fact that very little more flour was extracted.

The Exposition did reveal how far advanced in wheat-cleaning were the manufacturers located at Silver Creek, a small town not far from

Buffalo; but then everyone in milling, in this country and abroad, was familiar with that fact. It did show that the Smith-type sieve purifier with traveling brush was the favorite American machine in that category. The magnetic separator, introduced two years earlier, was prominently displayed, as were a chilled-iron millstone, under-runner millstones, and an electric purifier, which failed because it was indiscriminate in its removals. But the principal preoccupation of the Exposition visitors must have been speculation on what had happened in the western half of the Washburn A mill and what would happen in the eastern half.

Not perfectly satisfied with his A mill no matter how much it impressed some, and certain that gradual reduction could be adapted to American conditions no matter how much skepticism might have greeted his efforts to date, Governor Washburn first went to Europe himself to study the question. On his return he sent over de la Barre, who left Minneapolis in early July 1880 and was gone almost five months. De la Barre inspected many mills, and even took a workman's position in one Budapest mill for ten nights so that he might understand it better. On his arrival home on Thanksgiving Day, he rapidly completed his plans for the half of the eastern side of the A mill, which it was decided to complete immediately. The mill was originally designed to make six grades of flour, but after a few months the number of grades was reduced to three, the largest number for which there was then a market in America.

Things were humming in Minneapolis in those days, and the momentary center of it all was the Washburn A mill, as the following story from late in 1880 shows. We have slightly abbreviated de la Barre's recital:

"Soon after the starting of the Washburn A, Charles A. Pillsbury and his brother, Fred C. Pillsbury, called at my home one day while I was eating dinner. Charles A. Pillsbury said that he would like me to answer just one question, if I thought it was fair to do so.

"'Just tell me,' said he, 'from what you know about this Hungarian way of milling, if, in your opinion, we will all have to come to it. Consider the question well, as a good deal depends upon it.'

"I told the Messrs. Pillsbury that I was fully convinced that a change would have to be made from the old way to the new by all the mills, sooner or later. Mr. Pillsbury looked at me sharply for a minute, then shook hands with me, saying, 'Many thanks to you; I believe you are right.'

"I told Governor Washburn of this occurrence, and he said to me, 'You did perfectly right, de la Barre, and if Mr. Pillsbury asks you again to give him information, tell him the truth at all events and give him any advice you consistently can. My mills are only a small part of the whole, and I cannot make all the flour the people want, no matter how badly I should want to do it; and I have no liking for any dog-in-the-manger business.'"

A cycle of new building and remodeling of mills began, and in a year or two the Minneapolis output was more than quadrupled. The Pillsburys, of course, were not mere followers. Their remodeled Excelsior mill, completed by W. D. Gray in the spring of 1881 with a capacity of 800 barrels daily, incorporated the automatic, all-roller, gradual-reduction system—the first full-sized merchant mill located where it could contribute to the main stream of milling advance to qualify under all three categories; and the Pillsbury A mill, completed in its eastern half in 1881 and on its western side in 1882, became the world's largest mill, with a capacity of 5,000 barrels daily. Although the capacity of other mills was increased, almost invariably by improved machinery and processes rather than by physical enlargement of the plant, the Pillsbury A for many years maintained its leadership in size. This mill began on the system of six breaks, as compared with the present five, and made a limited use of millstones to reduce fine middlings—another example of the special difficulties encountered under gradual reduction near the tail of the mill. The Pillsbury A was the first Minneapolis mill to get steam power, in the winter of 1884. The Pillsburys were also American pioneers in wheat-mixing, from 1889, as well as in setting up a chain of country grain elevators.

As the capacity of the city's mills increased, the need for power became more insistent, especially in the late fall and winter, when the flood of wheat grew larger and the flood of water fell off. By 1892 sixteen of the twenty-one mills had been fitted with auxiliary steam power. It is a surprising fact that the full possibilities of the river were not utilized until 1896, when a dam farther downstream provided an additional drop of 20 feet, increasing the usual maximum power available from 25,000 to 35,000 horsepower.

We are fortunate in having figures, gathered by the Kansas Department of Labor, which throw some light on the increased use of rollers and of gradual-reduction methods in that state. The data cover only the period from 1885 to 1896, but are of special interest because it was just at this time that the hard winter wheat in this zone began to rival the hard spring wheat of the Northwest. The data follow and are charted in Figure 102:

	All-Roller Mills	*All-Millstone Mills*	*Combined Mills*
1885	4.8%	45.9%	49.3%
1887	11.1	27.4	61.5
1889	16.8	13.5	69.7
1892	32.6	7.1	60.3
1896	59.5	7.2	33.3

The rise of combined mills until 1889 was no doubt due in part to the continued spread of modified New-Process milling, where a few pairs of rollers would be added to flatten the germ or reduce some of the middlings. The figures are in terms of number of mills. Capacity figures would greatly

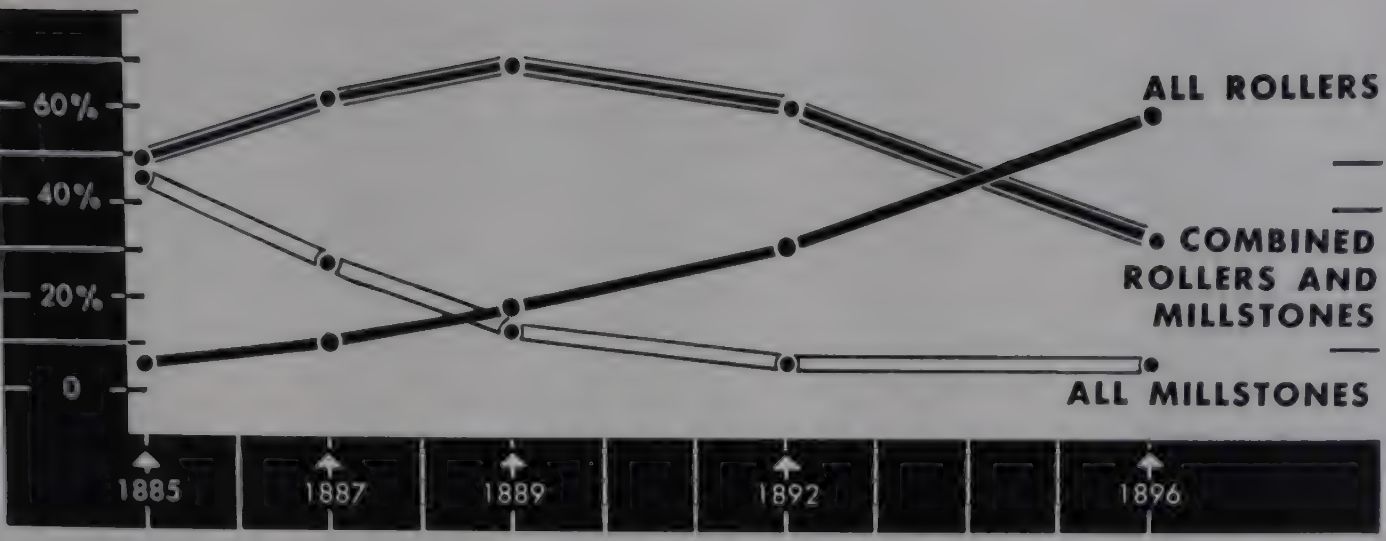


Figure 102. Changes in the character of Kansas mills, 1885–1896, as reported by the State Department of Labor.

increase the importance of rollers: as early as 1887 the Department estimated that "rolls produce nearly, if not quite, nine-tenths of the flour ground in the State." In 1888 the sixteen large merchant mills of the state used 420 pairs of rollers and only 34 run of stones. Toward the end of the century the millstone was rapidly passing out of use as an adjunct to rollers, and the annual rate of increase of all-roller mills had not yet begun to decline.

Although we have no detailed figures for the country as a whole, the Kansas data are probably representative. We do know that a single firm, Nordyke & Marmon, built over 1,000 complete roller mills in 1887–1889; that 25,000 pairs of Gray rollers were in use by 1888; and that 14,000 Case roller pairs had been sold by 1890. By 1894 85 per cent of the combined capacity of Minneapolis, Duluth, and Milwaukee was milled by Gray rolls alone.

During this period the milling capacity of the Northwest, and especially of Minneapolis, grew prodigiously. Whereas St. Louis and Minneapolis each produced about 2 million barrels of flour in 1880, over the next ten years St. Louis barely held her own, while Minneapolis quadrupled her production. And in the period immediately thereafter a new competitor with another new wheat—hard winter, instead of the hard spring of the Northwest, with Kansas City as its principal milling center—began to forge forward, aided by ever increasing numbers of the rollers that could reduce it. Although by 1883 the soft-winter-wheat millers were beginning to solve the problems set them by the new methods originally developed for hard wheats, the greatest future for American milling still lay in new lands to the west, as had been the case since colonial days.

The problems the miller of the 80's had to face in considering the use of rollers were extraordinarily perplexing and, in terms of the knowledge possessed by most of them, insoluble. For a long time he did not know what manufacturers he could trust, or even if their patents were good. If he turned for information to the scanty milling press, he was met for the most part by ill-concealed rehashes of advertising literature. Of the various sheets that appeared from time to time, two have endured to the present day. Though they began almost as house organs, the *Northwestern Miller* and the *American Miller*, both founded in 1873, grew up with American milling. No love was lost between them in their early years, but the files of both are necessary today for a better understanding of this confused period, and therefore no doubt both would have proved useful to a broad-minded contemporary miller.

The *Northwestern Miller*, published at Minneapolis after a brief start elsewhere, in the 80's and thereafter increasingly devoted itself to problems of interest to the new merchant miller who was coming to the fore. These were problems of purchase and sale, of freight rates and bills of lading, of pirated brands and improved packaging, of securing capital and remodeling mills. The *American Miller*, published at Chicago after a brief start elsewhere, was for many years the organ of the ordinary small miller; in the early days, to the great disgust of the *Northwestern*, its readers wrote in to debate the merits of burrs versus rollers, to decide whether mills ground faster at night, to discuss whether millers should also be millwrights, and to give their views on dozens of other deep questions. But its files nevertheless contain thousands of items of information now to be found in no other place.

But neither publication, nor indeed any other, gave anything like a concerted view of milling. Foreign works were largely unavailable except as capriciously rehashed in the milling press, and would have been useless if fully at hand, since conditions were so different. The nearest thing to a treatise was a series of articles written by Louis H. Gibson for the *Northwestern Miller*, and separately published as *Gradual Reduction Milling* in 1885. Gibson offered an admirable philosophy of gradual-reduction milling, which has stood the test of time surprisingly well; but his instruction was fuller of wisdom than of homely details – in article form it had been called *Rough Notes* – and it offered little help in the confusion of machines and machinery salesmen.

The detailed technical problems connected with the roller mill would require a book in themselves: problems of the best arrangement of the rollers – whether vertically, on the horizontal (as for the most part in the United States, where feeds are large and speeds of rotation high), or on the diagonal (as is usual in England); of roll lengths and sizes; of corrugations (Figure 103 – Wegmann by 1881 had collected 207 varieties); of proper installation and best method of drive; of the proper number of breaks and reductions – six breaks were usual here as against five now, as compared with four in England and as many as eight on the Continent

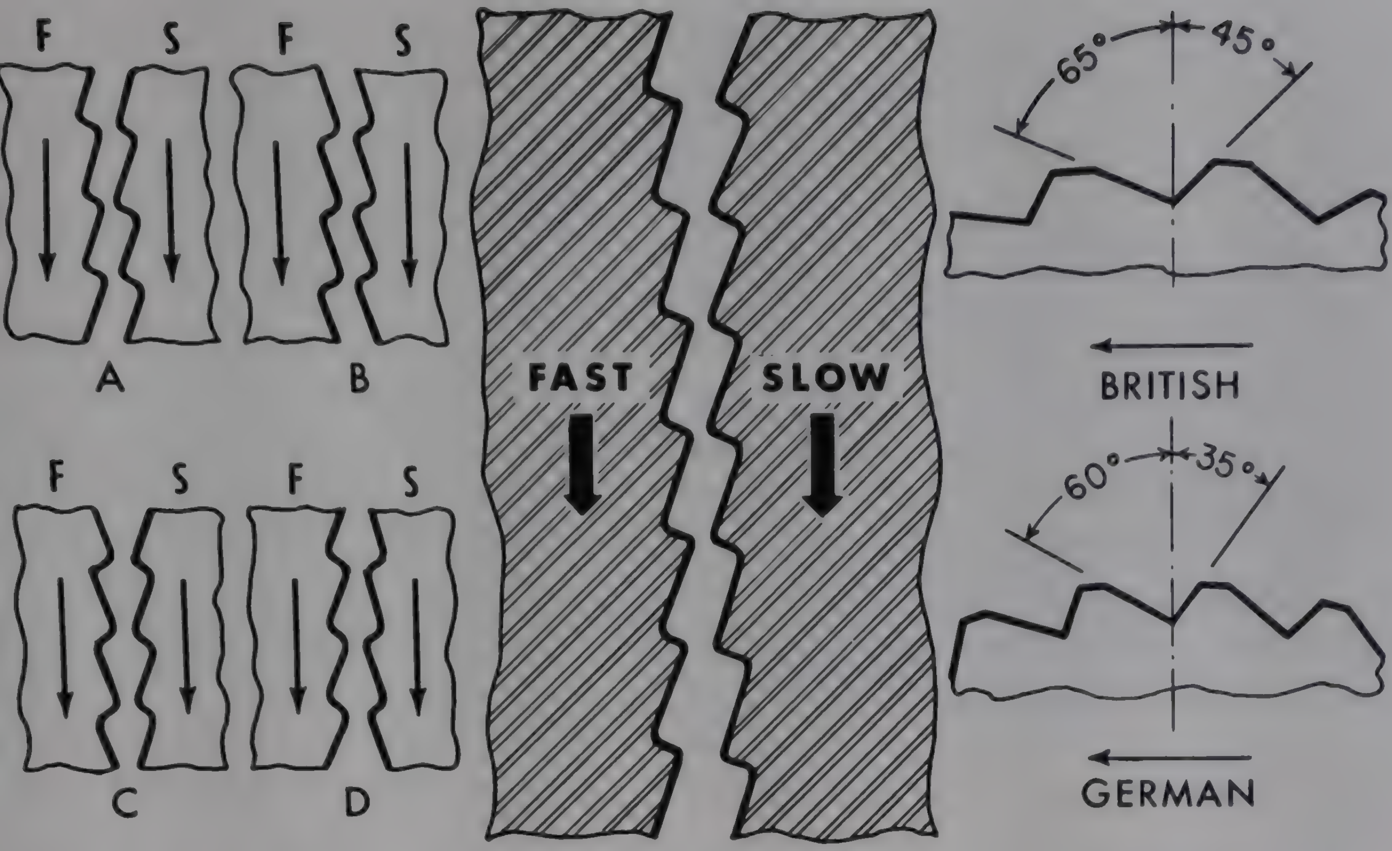
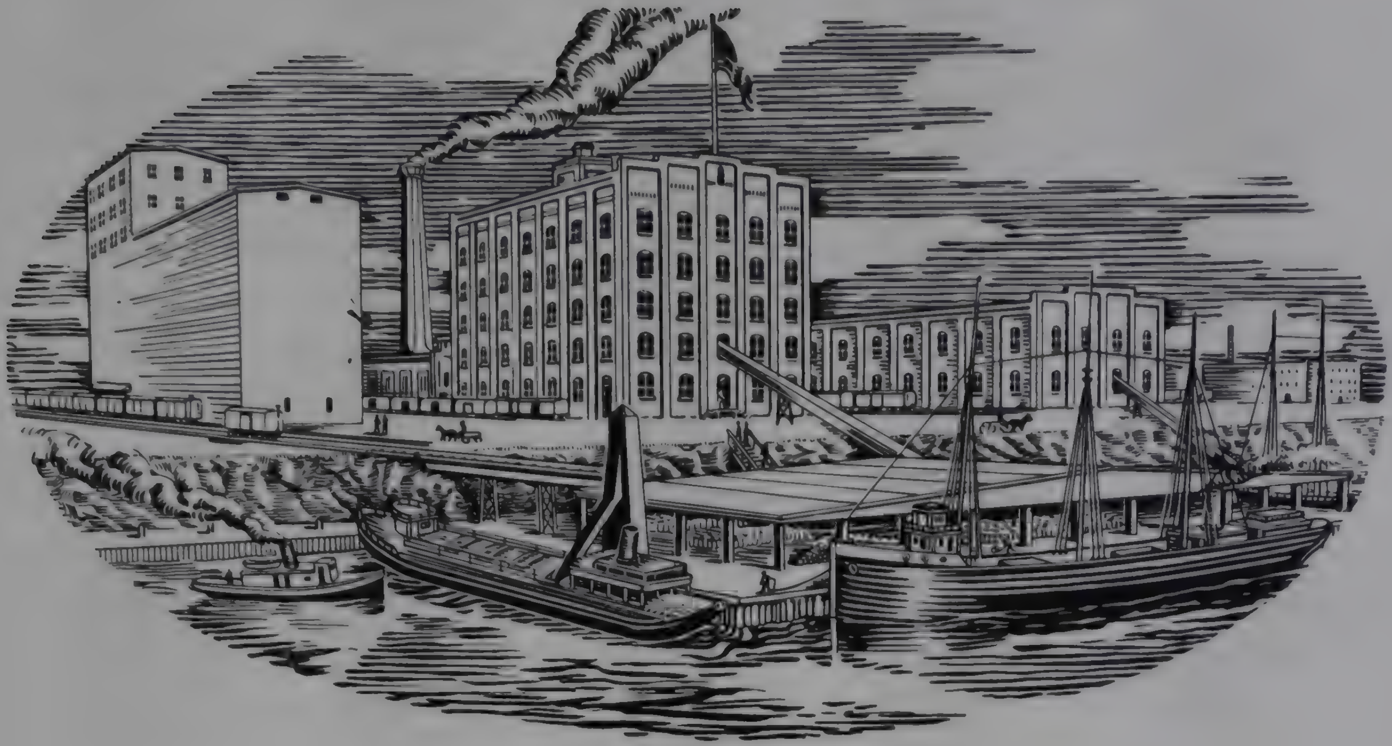


Figure 103. In the center, the typical corrugation of American rolls. At the left, running arrangements of the fast (F) and the slow (S) rolls: A, dull to dull; B, sharp to sharp; C, sharp to dull; D, dull to sharp. At the right, typical British and German roll corrugations; if these rolls ran in the direction indicated by the arrows, they would be rotating sharp edge foremost. The snubbed-off corrugation enables European millers to favor rolls set sharp to sharp.

(see Figure 124 for characteristic separations); of correct speeds and differentials at different points in the mill; of feeds and of air exhausts to cool the stock and rid it of dust; of all the many difficulties that had to be settled some way in the 80's, almost without benefit of experience. Consider the stern demands laid on the miller in charge of the break floor by a modern writer, and try to imagine his lot when roller milling was young: "Good breaking demands a constant watchfulness, the ability to perceive when a change is required, reasoning power to decide what change is necessary, and the courage to make the change."

These high moral and intellectual qualities had to be applied not merely to a single machine itself highly complex – even Wegmann's early roller assembly had over 600 parts – but with consideration of the effect that changes made at any point in the mill would have on the entire milling system. The old adage "As you grind, so must you bolt" was true in magnified degree of roller milling. Rolls running *dull to dull* would need to run *sharp to sharp* if a softer or damper wheat was being milled, if the conditioning department was doing a more thorough job, if a humid spell was coming on, or for a dozen other reasons that would have to be weighed before the change was made. Increasing the distance between a single pair of rolls might throw a greater burden on bolters and purifiers than they could bear, producing too rich tailings and upsetting that great desideratum, the balance of the mill; setting the rolls too close might make too much low-grade break flour, and once more upset the balance of the mill by giving succeeding machines too little to do, so that branny particles would pass through the bolting cloths or good stock be lifted to the dust collectors by the purifier fans.

The path of excellence in roller milling was strait and long, and even when faithfully followed did not necessarily gain a financial reward. For competition was unrelenting — the competition of ignorance due to inability to figure costs in a new situation, and the competition arising from the uncertainty of the market. Wheat is a commodity whose price is constantly fluctuating; the miller who had bought his grain at a high price might find his flour selling in the same market as that of millers whose wheat had cost them less. Large mills and small were therefore led by the spread of roller milling to engage in an apparently endless search for economies in every milling operation, and in the discovery and exploitation of every possible outlet for their products. The miller had no sooner partially mastered the difficult problems of production than he was forced to deal with equally pressing problems of economics, marketing, and supplies.



CHAPTER XVII

The Business Side of Milling Gains Importance

The battle for existence has been changed from the mill to the office, from manufacturing to the disposal of the product, from technique to finance, from brand to price.

—*Northwestern Miller* (1889)

Improved process requires improved management.

—J. Harrison Carter (1879)

IN THE new art of milling, two questions speedily came to the fore. How far should reduction be carried? This was given special point by the need to scrape the last possible bit of endosperm from the bran, because of increasing competition and because of a poor market for the final remainder of bran at the end of the process. The second question was even more urgent: how effect the many delicate separations required to take full advantage of rollers? Purifiers did a quality job of separating, but only if the stock sent to each one was already quite uniformly sized by previous separations—which meant that the problem was pyramided rather than

Chapter head oval. A mill of the National Milling Co., Toledo, Ohio, in 1895.

simplified by purifiers. Bolting thus became a leading preoccupation of the new generation of millers.

At first, bolting reels were the only recourse, and as a result they were multiplied unmercifully in a hopeless effort to handle a situation for which they were not adapted: they were highly inefficient, they were costly to operate and maintain, they occupied an inordinate amount of space, and they made an extremely dry flour, the bread from which quickly staled. Although nothing better was available for a time, from about 1880 the reel, "the last of the old-timers," was challenged in quick succession by a number of rivals.

One alternative, the centrifugal reel, first became widely known in the United States at the Cincinnati Milling Exposition of 1880. It had been invented in 1861 by Gustav Lucas, a German, but it was not much used in Germany until 1870 and its adoption abroad was slow until the spread of roller milling. The centrifugal consists of a slowly rotating cylinder, inside which a number of beaters revolve very rapidly, throwing the stock against the cloth (Figure 82). One aim in the centrifugal was to run the beaters at such a speed that the lighter contaminations would be kept in suspension, without ever reaching the cloth. The chief problems were air control in the cylinder and wear on the bolting medium.

After the George T. Smith Middlings Purifier Co. began to make centrifugal reels in 1882, their use spread very rapidly in the United States; by 1885 there were at least 8,000 in use and in several instances mills were completely outfitted with them.

As compared with that of ordinary reels their great capacity was an undeniable merit. On reduction-roll stocks, for example, they could do twice as much work for the same area of cloth. But it soon became clear that they treated most stocks too severely to permit their use in this country at any point except near the tail of the mill, where centrifugals can still often be found beating bits of flour loose from the bran. Even for this work they are frequently replaced today for soft, fuzzy stocks by short-throw, high-speed gyratory sifters derived from the plansifter we shall shortly discuss. In England, where milling stocks are damper as a rule than in the United States, centrifugals are still used farther forward in the mill.

Centrifugal reels figured in a short "bran-cleaner epoch" which lasted from about 1879 to 1885 as the premium on patent flours declined, requiring economy in handling other parts of the grind. Rollers cannot "finish up" the stock: "There is always a residuum of material or tailings, *Ueberschlag* as the Germans call it, made by the corrugated rolls themselves, which the miller barely knows what to do with." It was essential to recover as much flour as possible from this material. The ever ingenious Jonathan Mills invented a disintegrator pin machine for bran cleaning (Figure 92); and in 1898 the scroll mill was developed as an application of disintegrator principles applied to the millstone form, for this and other purposes. It consisted of two small metal discs, fitted with corrugations or blades near their outside circumference, through which fuzzy, flattened materials from the breaks were passed to liven them up for further grinding on rollers. A very useful machine for cleaning the bran is the bran duster, in which brushes rub the stock against a fine wire cloth (Figure 82); the action is less severe than with the centrifugal, since it scrubs the stock instead of throwing it against the reel cover.

A new lead in effecting separations was suggested by the Morse bolt patented on March 14, 1882. In this machine a series of small elevators fed stock continuously to a slanting flat sieve, picking up the overtailings and dropping them onto the sieve farther down the machine. The apparatus needed a first-rate mechanic to run it, or the elevator buckets would get out of line, jamming the machine; but when running well, it did good work and set men to thinking. One result was the inter-elevator reel, in which the stock was lifted for bolting by a device located inside a bolting cylinder — not thrown as in the centrifugal reel. Jonathan Mills was first in this direction when in early 1884 he offered a reel containing a large wooden core with a coarsely serrated surface which, as it rotated, lifted stock from the bottom of the reel in the spaces between the serrations, and spread it over the bolting cloth. The great weakness of these machines was that they would load up with stock at the bottom, all but ceasing to bolt. W. D. Gray's "flour dresser" was of inter-elevator type (Figure 104), and was still being installed in mills in 1900 at a time when a vastly more versatile bolting arrangement on a much sounder principle had already been available in Europe for over a dozen years and in this country for eight.

By far the best bolting motion is the gyratory action natural to the human arm when using a small hand sieve. Gyration covers substantially all the sieve surface and gives the stock a maximum chance to reach the meshes without unnecessary travel. Flat sieve bolters of a sort had for long been known to millers: La Croix had used them at Faribault, they were common in the American-type purifier, and very long ones had been installed in the 1880 Washburn A mill. In fact, there was continuous approval of flat sieves for scalping purposes — to rid a stock of its larger bits before closer grading and dressing of the remainder.

The obvious problem with a flat sieve was how to get the desired gyratory motion in a machine that would have capacity and be able to handle a variety of stocks. A less obvious but equally important problem was that of avoiding excess vibration in a large-capacity machine. These problems were solved in principle in 1888 by Carl Haggenmacher with his plansifter. By a brilliant stroke he hung his machine from flexible rods, and drove it from the center underneath, counterweighting the gyrating parts to

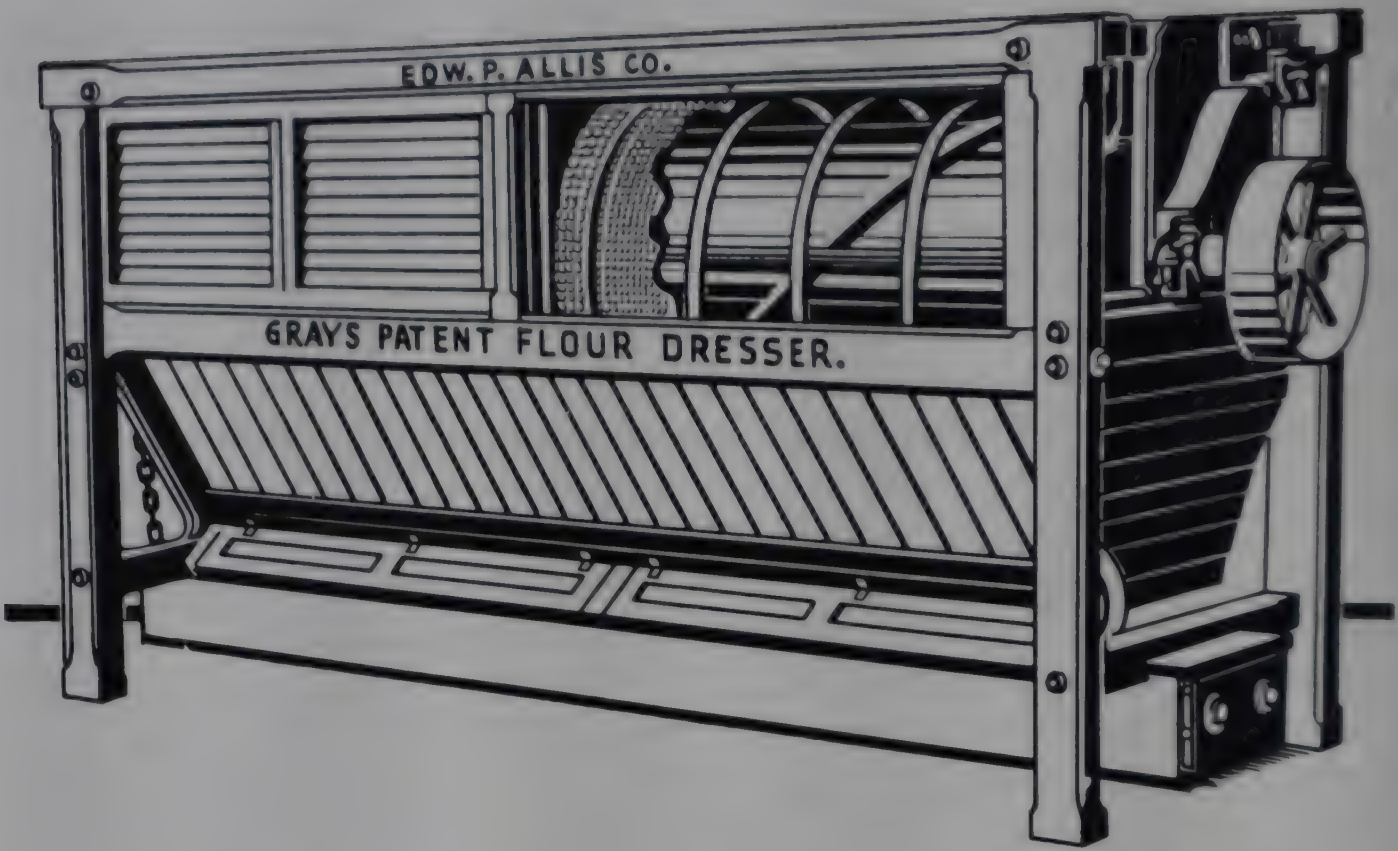


Figure 104. Gray flour dresser, a variety of inter-elevator reel. As the cutaway view shows, there was a sheet-steel drum inside the bolting cylinder, around which ran a number of spiral carriers, which also acted to convey the stock through the reel. As the drum rotated along with the outside cylinder, the stock was gently spread over the cloth, for the most part on the up side.

dampen vibration. His method of causing the stock to move along his flat sieves was extraordinarily simple (Figure 105). The plansifter effects separations in a more rational manner than a reel, does it more efficiently, and has much greater capacity.

Though Haggenmacher's early machines were heavy, clumsy devices compared to modern sifters, they set an entirely new pattern in effecting separations, and gave roller milling and the purifier the ally they needed in the bolting department of the mill: the plansifter and its modern derivatives made possible the separation of the stocks produced by the former according to their common needs. It was the introduction of the plansifter that convinced most European millers that sizable mills could operate satisfactorily on an automatic basis.

In 1892, when 1,500 plansifters were already in use in Europe, a single machine was installed in the Pillsbury A mill, where it scalped, graded, and finished the flour for the entire third break of a 1,200-barrel mill, displacing four scalping and six grading reels. The Pillsbury people thereupon obtained a contract entitling them to make 150 of the machines. In June 1892 Barnard & Leas secured all other American rights to the apparatus. By May 1894 the Pillsbury A mill had been completely equipped with 90 plansifters, as a result of which there were eliminated "300 reels averaging 14 feet long, 900 pairs of gears and the numerous upright shafts driving 600 short conveyers, 50 scalpers and graders and 20 centrifugal reels. By the mill being thus lightened up, it is estimated that it can be operated with 200 horsepower less."

The introduction of the plansifter again threw the American milling world into turmoil, and mill furnishers racked their brains until they found alternatives to Haggenmacher's flights, which were one of the few patentable features about his machine—the gyratory motion used was, of course, familiar and open to all inventors. They came up with a number: inclined

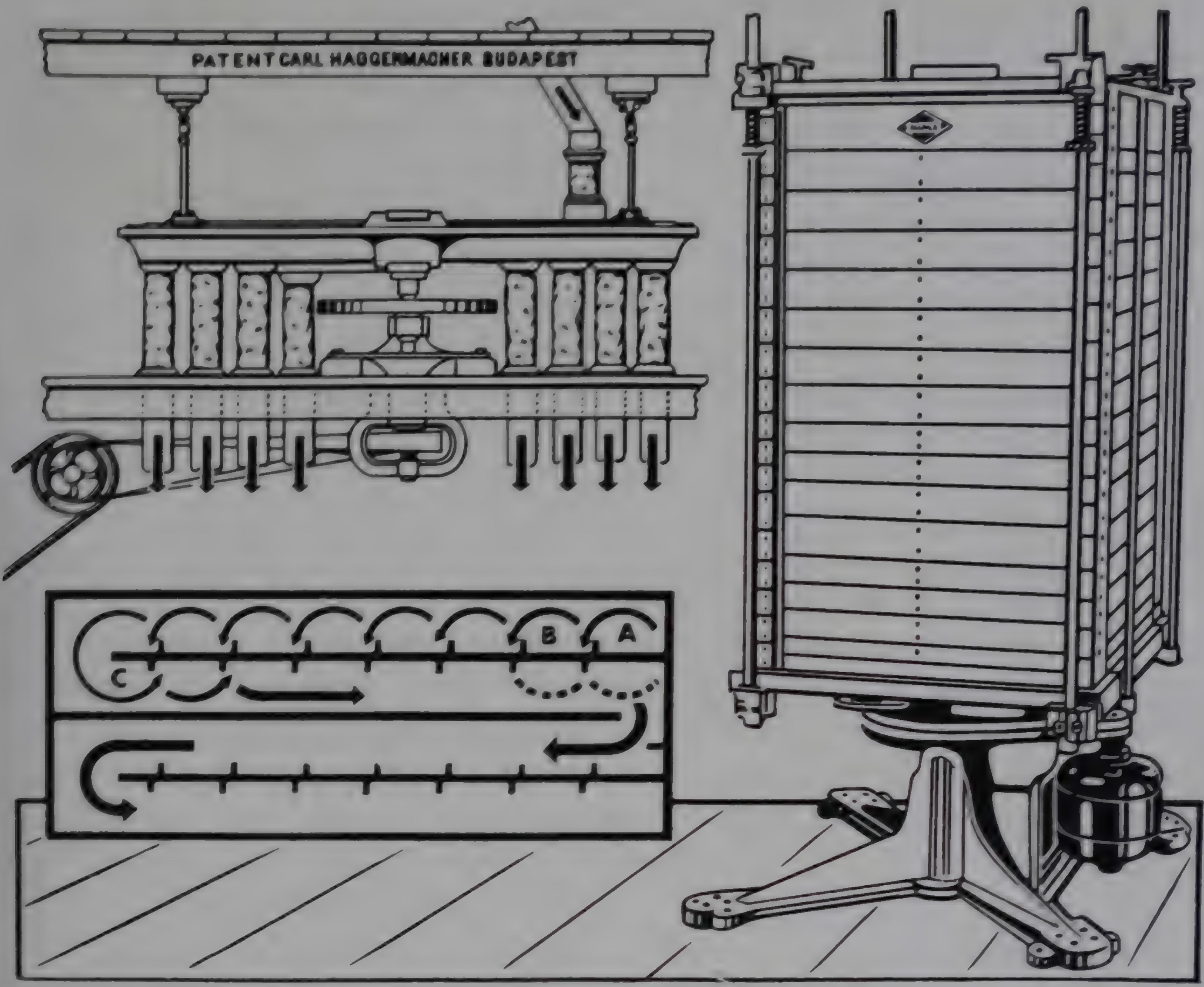


Figure 105. At the left, early Haggenmacher plansifter. Stock entered the upper section of the machine, which was gyrated by the belt drive, and fell onto a sieve like the one schematically indicated in the insert. Entering at A, the stock would, by the circling of the machine, be made to swing ahead to B, where it would be prevented from returning to A by the center barrier and the outward projecting flights. In this manner the stock would walk along the sieve, reversing its direction at C as shown. Throughs and overtailings left the machine by the stockinged outlets below. At the right, a view of a modern high-speed sifter which, though greatly altered and improved, works in the same general way as the Haggenmacher machine. The entrance and exit stockings are not shown, since their number and location would depend on the use to which the machine was put.

sieves, a cylindrical machine in which centrifugal force moved the stock, etc. In all bolters, and especially in those with flat sieves, the cloth must be kept from clogging, if possible from the under side. Various schemes were devised for this purpose. During 1898 90 per cent of the new plants erected in the United States used some type of flat-sieve bolter, but even so it was far from monopolizing the field. In 1886, just before the invention of the plansifter, it had been estimated that American millers were still using over 140,000 six-sided reels, a type even older than the common cylindrical reel of inter-elevator type. As late as 1905, 30 hexagonal reels were still at work in the Washburn C mill.

The changes we have been observing, along with those occasioned by the introduction of the sieve purifier, created a need for stronger bolting cloths, which was met by producing XX and XXX cloths with sturdier threads, together with the superior grit gauze which was first imported into the United States in 1872.

In addition to bending every effort to extract more flour, millers tried to improve the market for the inevitable residue of bran as a cattle feed. They publicized its high protein content, raised herds on diets centering in bran, offered prizes for machines to compress it so that it could be economically shipped to England, where in 1880 it was worth five times as much as in Minneapolis. Over the years, with the help of government bulletins, they managed to convince farmers that cattle would benefit from being fed on those parts of the wheat berry not easily digested by man. Today milling and farming would both be unthinkable without our large consumption of cattle feeds derived from wheat.

The search for greater economy, of course, affected other phases of the milling process. As mills grew larger, enough of certain stocks could be counted on to justify a greatly extended use of the purifier in its three

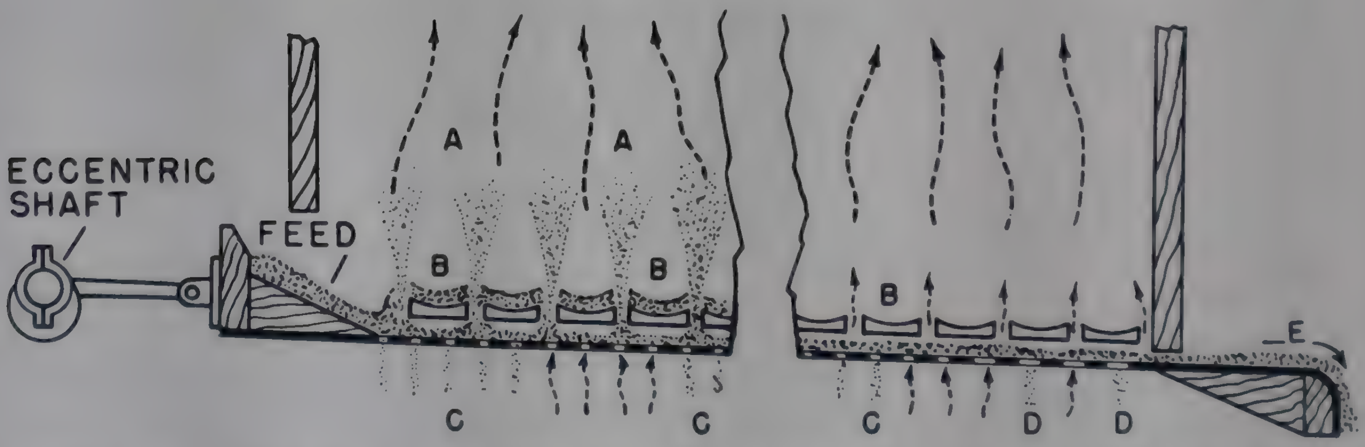


Figure 106. Cross section of a tray purifier, a much used English type. The trays B catch the heavier stock raised by the air currents, so that only light material passes by way of A out of the machine. The finer middlings pass through the sieve at C, while the coarser middlings fall at D, and still larger particles needing further treatment overtail at E.

functions of the primary purification of break stocks, after they had been scalped and graded; of secondary stocks from reduction rolls, after grading; and of stocks from other purifiers. Over the years serious charges have been levied against the forced air purifier: "The device has been arraigned as a robber of moisture, a contributor of dirt, and a waster of power. It has been accused of gathering together large quantities of smoke, soot and other undesirable foreign material, depositing the same upon the surfaces of our otherwise clean middlings, and thus increasing the ash content, and destroying the bloom of our flours."

In spite of these criticisms few mills of any size are built today without including many purifiers. From time to time gravity machines of the Haggenmacher type, called "Effective" purifiers in England (*cf.* Figure 87), were tried. Return-air or "air-belt" purifiers were invented about 1885 — self-enclosed machines using the same air (very nearly) over and over; and in England about 1886 Simon offered a purifier with trays just over the sieve to catch the heavier liftings (Figure 106). With finer separations, improved fans, and dust collectors less subject to back pressure, the work of the purifier has become more reliable.

The problem of back pressure in dust collectors was largely solved in the early 80's by Faustin Prinz, who arranged a number of cloth cones in a circle to collect the dust brought to them by a fan, and had each one tapped mechanically while it was isolated from the air chamber (Figure 107). When the cones are not allowed to become clogged, the lifting power of the air remains fairly uniform. The cyclone dust collector, an extraordinarily simple device with no moving parts (Figure 95), was invented by O. M. Morse and first marketed in 1886. As the dust-laden air enters the cone at the top, it swirls about the air chamber and the dust is brought to rest by friction on the sides and slides down to be conveyed away. Because cone collectors are efficient inversely to their size, nests of very small cones have been put together in some machines; also of late years more efficient collectors with very long cones have come into use. Since ordinary cone collectors are only from 70 to 90 per cent efficient, their use is hardly justified on valuable dusts; but they nevertheless can well perform many functions in the modern mill.

The greatest change in wheat-cleaning in the period before 1900 was to be found in the refinements in wheat-washing introduced principally by the English, on account of the very dirty Indian wheats they often had to handle. In 1878 the noted German authority Frederick Kick had strongly opposed wheat-washing; and in 1888 C. A. Pillsbury was able to assure Europeans that Americans never dampened their wheat before grinding — except, of course, the millers of California, whose very hard wheat would not grind at all without moistening.

There was good reason for caution in wetting wheat, since wet grain

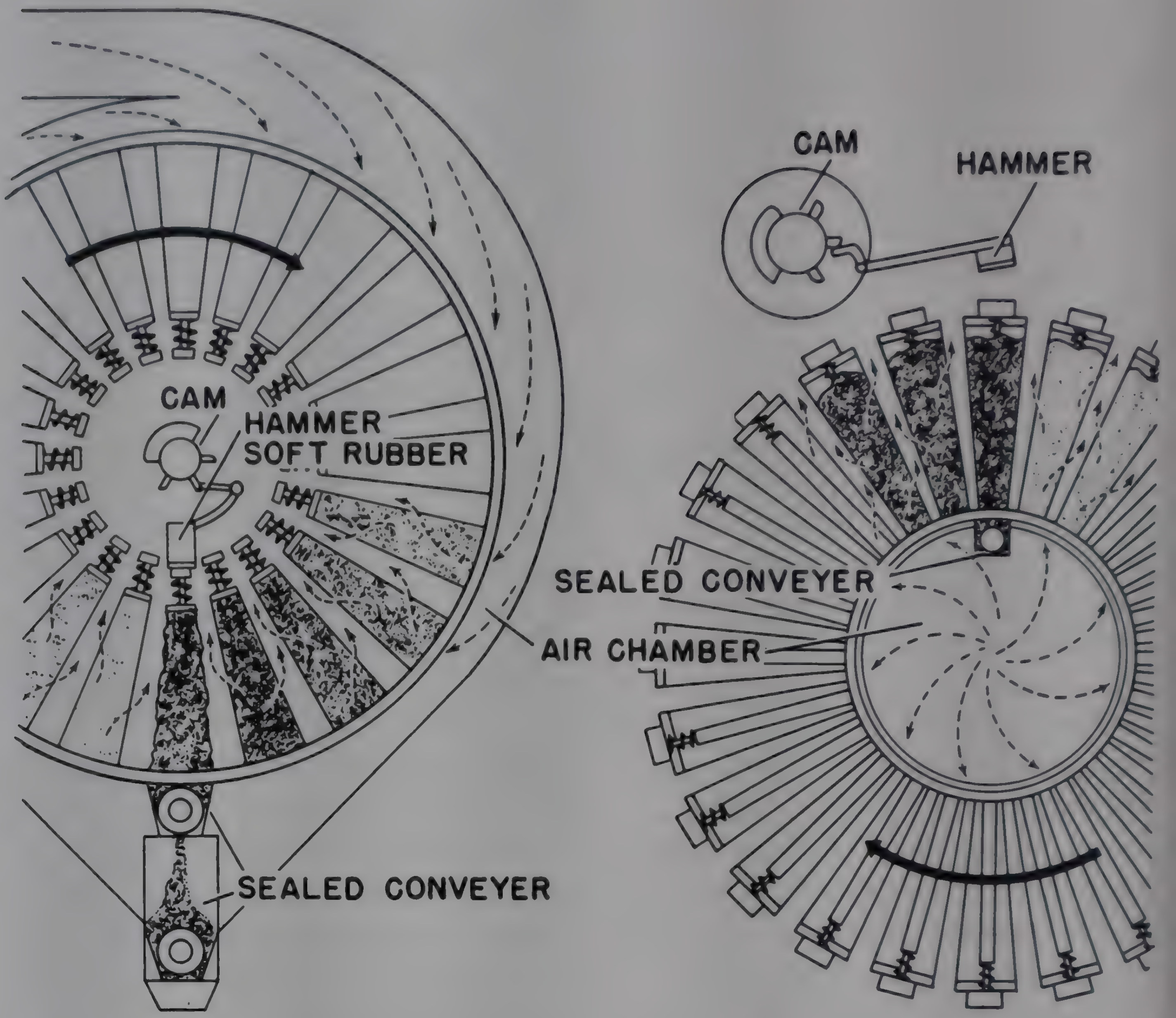


Figure 107. Cross sections of tubular dust collectors of the type first developed by Faustin Prinz in the early 80's. Dust-laden air enters the nest of cloth-covered tubes either (at the left) from their outside or (at the right) from their inside ends, and deposits the dust on the tubes as it filters through. The cylinder of tubes, composed of many units like those illustrated, slowly rotates, so that each tube is brought over a sealed conveyer, where it is tapped by a hammer and relieved of its dust. The sealed conveyer largely prevents back pressure.

is liable to ferment, spoiling the flour; the milling process may be made more difficult, or the keeping quality of the flour affected. But under stress of necessity English millers have learned not only to clean wheats by washing, but also to alter their character by removing or adding moisture or heat. The Englishman uses this conditioning constructively to improve the strength and baking quality of the flour, prescribes special forms of treatment suited to individual wheats, makes mill mixes out of a half-dozen or more kinds of wheat drawn from all over the globe according to price and what they can contribute to his flour, and in general is a versatile master of the possibilities of diverse wheats.

In all this confusion of new machines and processes, roller milling ran right away from the average small miller. He saw himself doomed if he failed to adopt rollers, by the mere prestige of the new method if nothing else, but also by the superior quality of roller flour. Talk as you might about the nutty flavor of millstone flour, most people preferred to buy the whiter loaf with its bland taste. To make a full roller mill pay in 1881, it had to produce over 125 barrels a day. Most millers didn't have the capital to set up such a mill, and many simply didn't want to extend themselves so far. To the little fellow, the so-called short system, which had a great vogue in the early 80's, therefore appeared to be a godsend; it gave him rollers at a cost more nearly within his means, in a mill more nearly suited to his inclinations.

Charles Huber has been called the father of the short system. A traveler for the Jno. T. Noye Mfg. Co. in the soft-winter-wheat territory—a region in which roller milling was at first reluctantly adopted—Huber in 1881 planned a number of mills on three breaks and five reductions. In 1882 J. M. Case erected the first two-break mill. After this start, in two or three years about half of the mills in some parts of the soft-wheat region were short-system mills of one kind or another. The one plain fact these mills had to face was that close grinding did not result in a high yield; it meant instead a rich feed and a great deal of poor flour. But at the head of the mill it was possible to produce a grade of flour, in smaller quantity, equal to that produced by much longer systems. Even on the short system a good deal of machinery was needed. Aside from machinery for cleaning the wheat and packing the flour, Case advocated no fewer than eighteen items, including eight pairs of rolls; he was willing to consider equipping the heart of a mill with an absolute minimum of nine machines, including four pairs of rolls.

Though the short-system phase of American milling had largely ended by 1890, it left two significant marks on our milling practice. It showed that somewhat closer breaking was possible, with the result that more floury matter was kept away from the bran bin and the dust collector, and therefore it helped American millers to settle on five breaks as a norm instead of six. In the second place, by using longer break surfaces, as Louis H. Gibson noted in 1886—up to 30 inches or more—short-system millers encouraged others to do likewise.

Truth to tell, roller milling was not for the poor man or the average small miller. With the passing of the years more small millers were pushed to the wall than survived, as is clear from the decline in the number of small toll mills from the 23,661 enumerated in our 1840 Census to the 15,782 listed in 1900—a huge drop when we consider the great expansion of settlement in new territories after 1840. While we do not have figures for intermediate decades, there probably was a rise in the number of grist mills until 1870, or even later; merchant milling is not suited to frontier regions where transportation facilities are poor, as was the case in many parts of the United States until the late 80's. If the 24 per cent decline in grist mills reported between the 1900 and 1910 enumerations can be trusted, it suggests that much of the decline recorded for the preceding sixty years took place during the last quarter of the nineteenth century. Although the number of merchant mills was increasing during that period, many thousands of grist mills were closing. The era of the small mill, serving the farmers of its neighborhood for toll, was drawing to an end.

From 1840 to 1900 merchant mills grinding grain of all kinds for sale increased from 4,364 to 9,476. It appears that merchant mills increased somewhat slowly in numbers for the first decades following 1840, and that the pace then quickened, as our Kansas figures (page 254) indicate. By 1910, when merchant mills numbered 11,691, they were running neck and neck with grist mills, which stood at the almost identical figure of 11,961. The increase in merchant mills at a time when grist mills were disappearing was due to the fact that competition, a growing factor in milling, was eliminating the weak and inefficient and favoring well-organized, economical, large-scale operation, as it always does. By 1941 the average American flour mill represented a gross investment in land, buildings, and equipment of over $400 per barrel of daily capacity ($200 per cwt.).

In the effort to sell their products the larger mills, and more especially those of Minneapolis, began a vigorous search for markets, and gave particular attention to Great Britain, where the home production of wheat was increasingly unable to feed the rapidly growing population. As early as 1877 Governor Washburn had sent W. H. Dunwoody to Great Britain to solicit direct orders for flour, to be sent on through bills of lading, at a saving of from thirty cents to one dollar per barrel in commissions and transfer charges. Although it was cheaper to send a barrel of flour in this way from Minneapolis to Glasgow than to the Red River region, 300 miles upstate, where the wheat in it might have been grown, Dunwoody had the greatest difficulty in obtaining orders and found it necessary to deal directly with bakers to get American flour introduced. The English were already importing a great deal of high-quality flour from Hungary and, although this flour was expensive, it had monopolized the rather limited market for an excellent product.

Even as early as 1785 the American position with respect to wheat and flour exports had been voiced by Jefferson, who wrote that we could "sell the flour ready manufactured for much less than the wheat of which it is made. In carrying wheat, we carry also the bran, which does not pay its own freight." For this reason, up to 1845 very little wheat was exported from the United States as compared with flour, and even in that year the ratio of wheat to flour was less than 10 per cent, the flour being expressed in terms of the wheat required to make it. From then on wheat exports increased rapidly and flour exports but little, with the result that by 1880 the amount of wheat exported as flour was only about 20 per cent of the total.

Until about 1840 only one sixth of our export flour went to the United Kingdom, by far the biggest amount being shipped to the West Indies and Brazil from mid-Atlantic ports. During the Civil War, when our exports were for the most part cut off, Budapest millers largely took over our Brazilian market, and in the 70's they acquired the lion's share of the British import trade. By 1880, however, we had increased our shipments to the United Kingdom until it was receiving about three fifths of our total exported flour. Our large mills came to depend on the export trade; whereas it equalled only 17 per cent of our milling capacity during the 70's, in the next decade it increased to over 28 per cent. During the 80's and 90's, in exporting wheat and flour from our Northwest "we were conducting the most stupendous bargain counter in the history of agriculture." Minneapolis exports were especially heavy—they rose from 1 million barrels in 1881 to a maximum of 4,700,000 barrels in 1900. During the entire period from 1881 to 1900, about one third of the output of Minneapolis mills was exported, or an average of 2,700,000 barrels per year, almost all to the United Kingdom. We were cutting into the Hungarian market severely: between 1888 and 1892 Budapest exports of flour to Britain were almost halved, while American exports were almost doubled. In 1889 our best patents brought a higher price in Britain than did the famous Hungarian flour No. 0—because the capacity of our flours to absorb water was greater.

Throughout most of this period, export trade was maintained in the face of great obstacles. The shippers preferred to carry wheat and favored it in their rates, as they still do: in 1901 the differential was 6½ cents per hundred pounds. Shipments of flour were often delayed for months, and when they not infrequently arrived in damaged condition, there was little recourse under the terms of what W. C. Edgar, editor of the *Northwestern Miller*, called "the Captain Kidd bill of lading." Edgar was something of a versifier, and it was probably he who wrote the "Ballad of the Adventures of Flour on the Overseas Voyage" which appeared in his magazine in 1891:

It was a sack of Jones' Best
  That sailed the wintry sea,
And it had been from home two months,
  And near approaching three.

And when it had been carry-ed
  For quite three thousand mile,
The skipper opened up a port
  And soaked that flour awhile.

Then put it on the deck to dry,
  And when it grew quite hard,
He moistened it with kerosene
  And mixed it well with lard.

The crew was pleased to spit upon
  This bag of Jones' Best,
And of the jute which compassed it
  A sailor built a vest.

When it arrived at Liverpool,
  Where it had long been sold,
With crowbars and with iron picks
  They dug it from the hold.

They tossed that bag of Jones' Best
  Upon the busy dock;
It much resembled building-stone
  Fresh tunneled from the rock.

The buyer came and paid the freight,
  And, lest he's have to pay
An extra charge for quarrying,
  He quickly sped away.

All honor to that document
  Which makes the landsman swear;
That bulwark of the British Tar,
  That bill of lading rare!

Thanks largely to the agitation of the *Northwestern Miller* over many years, the Harter Bill was finally enacted, requiring a fairer bill of lading on American ships after July 1, 1893; and when "all risks" insurance was offered in 1894, giving complete protection against any loss from point of origin to destination, shippers quickly adopted protective standards and devices in the interest of lower premiums.

The export trade encouraged American millers to pay more attention to the demands of the market. For example, it was the cause of their giving up barrels in favor of bags, at a direct saving in 1892 of about nineteen cents on every 196 pounds of flour. The container, whether bag or barrel, at that time cost the miller more than the labor required to make the flour. The Hungarians were the first to ship their export flour in sturdy burlap bags, at a saving of about 10 pounds in freight charges per bag, and with far less chance of loss by leakage if the bags were handled properly. The barrels in which we sent our first flour to England were all but useless there, whereas the bags had a resale value. Until 1880 the demand for bags was so small at Minneapolis that none were made locally. For a long time thereafter, practically all the burlap used in the Western world was manufactured in the vicinity of Dundee, Scotland, because of the special experience required to manipulate the extremely refractory jute from which it is made. Even as late as 1900 Minneapolis millers needed more than 3 million barrels every year; on the wagon and rack shown in Figure 108, one team of horses could easily haul 200 empty barrels. Though flour is seldom sold in barrels today, the 196-pound barrel remained in use as a statistical unit until World War II, when War Food Order No. 1 substituted the short hundredweight of 100 pounds (cwt.), very much to the satisfaction of millers generally.

The export trade gave special point to transportation differentials accruing through favorable location or special treatment of mills. For a long time the railroads granted Minneapolis firms milling-in-transit privileges; grain was carried to her mills and the flour manufactured from the grain moved to its destination under a single through freight rate. Minneapolis millers were also allowed to store flour free over the winter at Buffalo – a great advantage, since they could mill and ship large quantities by the cheaper Great Lakes route in the fall and early winter, after the new crop had begun to arrive and before the Lakes were closed by ice. The Northwest was severely hit from 1901 on when its transit and storage privileges were curtailed, when the Elkins Act forbade rebates, and when milling-in-bond was permitted at Buffalo, so that mills there could manufacture flour

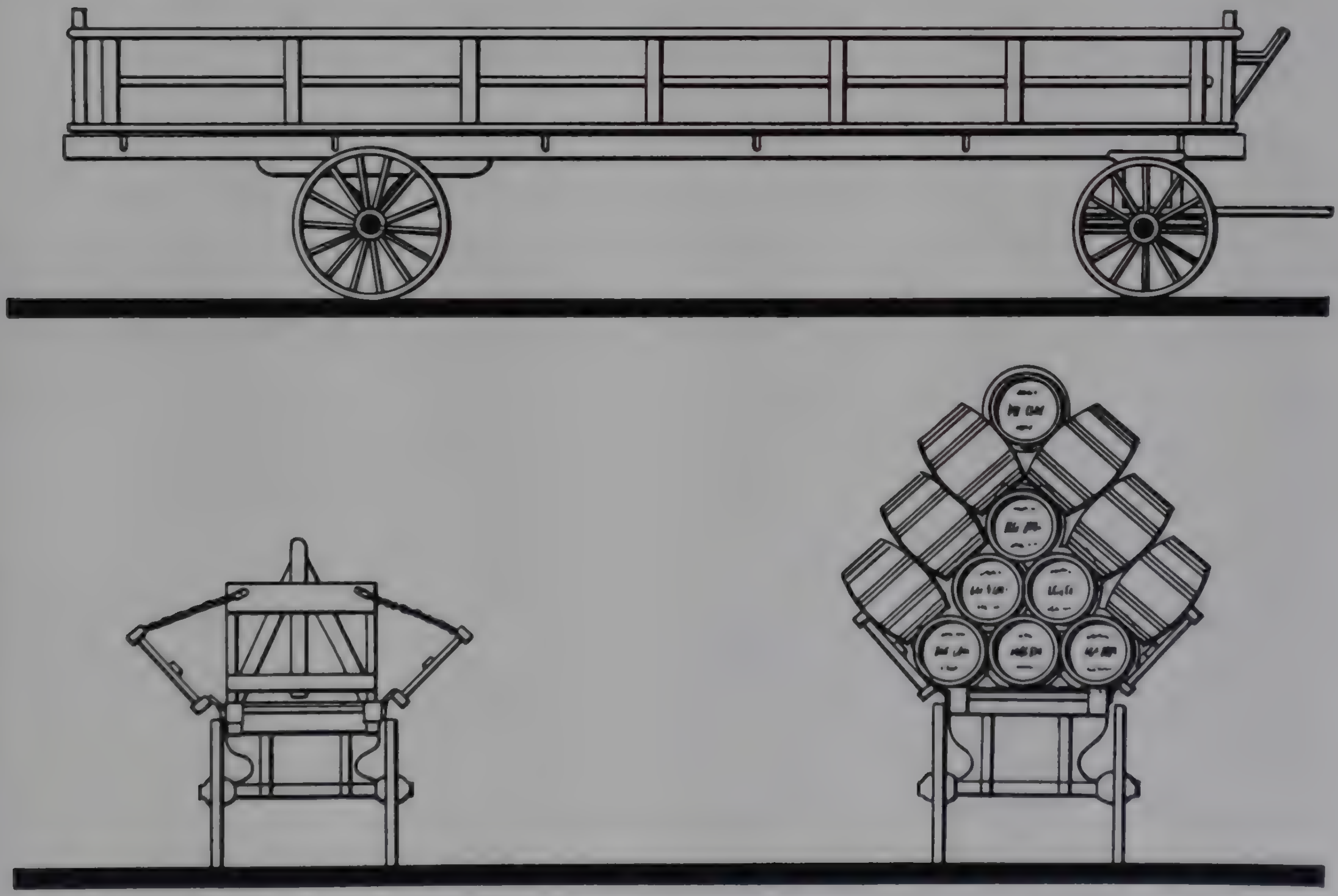


Figure 108. Wagon and rack used in the 90's in Minneapolis to haul flour barrels.

from Canadian wheat without paying the duty if the flour was not sold in the United States. In order to get their share of Canadian business, the larger Minneapolis millers set up establishments at Buffalo. This gave impetus to that policy of decentralizing milling facilities, along with concentration of control, which has been characteristic of the twentieth century in this country.

Simultaneously with these blows, the export trade to the United Kingdom began to fall away with the growth of roller milling there. The prophets of roller milling in England had for the most part preached in vain until the coming of "the ubiquitous bag of American flour." Whereas there were not more than 20 mills using rollers in the British Isles at the end of 1882, England four years later had at least 600 roller mills, many of course still using a few millstones. In the ten years to 1892, Henry Simon alone supervised the construction of 368 such mills at home and in the colonies. In England one result was the milling of greatly increased quantities of foreign wheats. Whereas but 20–25 per cent of wheat milled in a typical English mill was foreign in 1857, by 1877 50 per cent was imported, and by 1887 75 per cent.

The results of the transformation of English milling were eventually all too apparent in America. In an 1896 editorial the *Northwestern Miller* somberly stated: "In these times it is the exception, rather than the rule, for the miller to get out even on his export sales. He takes orders for foreign shipment simply to get rid of his surplus, and, if possible, keep his mill running steadily. The entire transaction is simply made in order to keep the wheels moving, in hope of something better in the future."

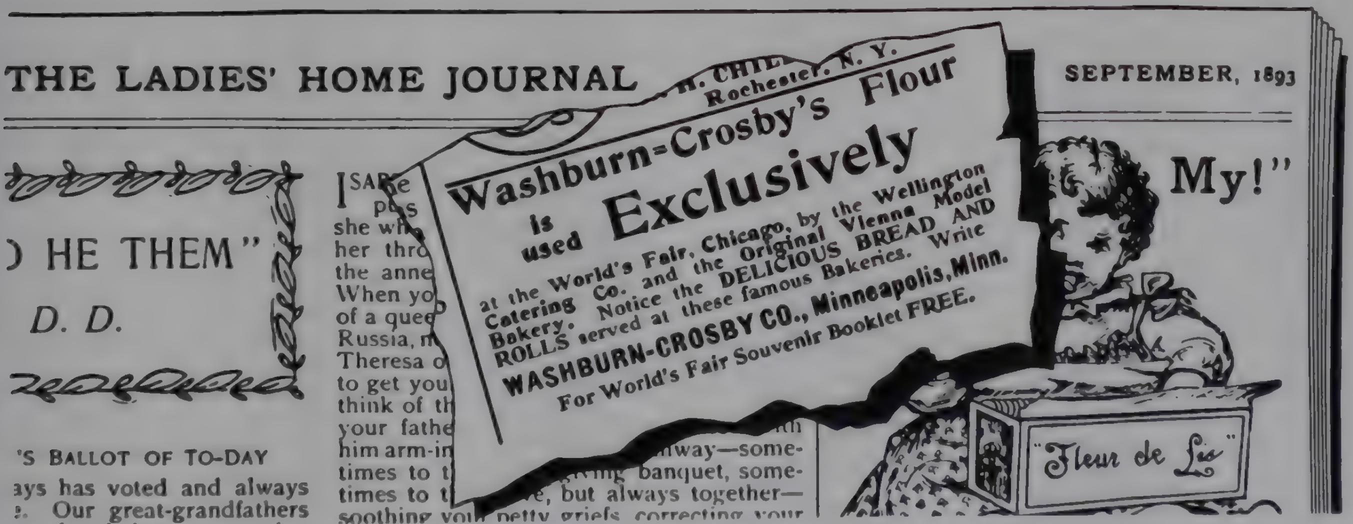
The hope was not to be realized, so far as the export trade was concerned. In the first years of the twentieth century, imports of flour into the United Kingdom from all sources began to decline as compared with wheat imported. By 1905 only 10 per cent of English wheat was imported as flour, in contrast to the 20 or 25 per cent figure which had prevailed as American flour exports rose in the 80's. The great days of American export not only of flour but of wheat to the United Kingdom were drawing to a close, since she increasingly satisfied her need for both commodities from within the British Commonwealth and by home manufacture, or, in the case of wheat, from the Argentine.

Nor did total American flour exports maintain themselves in the years that followed, except for a temporary increased demand consequent on the two world wars. While our production of flour fluctuated but little from an average of 113 million barrels a year over the period 1914–1939 (Figure 114), our exports of flour declined from about 12 million barrels a year for the period 1911–1914 to a low of less than 5 million barrels yearly for 1932–1936, and only under the stimulus of New-Deal subsidies for a short time thereafter managed to rise to the earlier level. In practically every

European country flour and wheat from nonsatellite regions were subjected to powerful discriminations, as the world moved into ever more closely managed economic systems. Under the stimulus of postwar scarcities abroad, American exports of flour and wheat have, of course, greatly increased since 1945, though without promise of permanence.

As the foreign market faded, and to a certain extent even before, large millers in the United States began to cultivate the home trade. For many years even large mills made no effort to sell their products in domestic markets outside of their immediate vicinity. Flour was usually consigned to brokers for sale at their discretion, and millers often had reason to be dissatisfied with the result. In 1882, however, the first branch office of Washburn, Crosby & Co. was opened, in Boston. In 1893 its successor firm, the Washburn-Crosby Co., was the first to initiate national consumer advertising of its flour by purchasing a one-inch space for a single insertion in the Ladies' Home Journal (Figure 109).

By that time flour was already being sold for home use in smaller than full-size 196-pound burlap sacks. The small cotton grocery sack of earlier days had been displaced in northern stores by weak paper bags during the Civil War when cotton became scarce; but it was not until some time thereafter that paper bags strong enough to hold a quantity of flour were made out of used Manila rope, of which rigged ships provided a prodigious supply. We are told that packers considered 24½-pound bags "a pestiferous contrivance" as late as 1885, and in 1897 a Minneapolis flour drummer complained strongly of the unusual demand for 6-pound bags of flour in Cincinnati. Nevertheless the trend continued; a 1948 survey, including export shipments, all in large sizes, showed that approximately 6 per cent of all American flour is sold in packages of 10 pounds or less. As many



THE LADIES' HOME JOURNAL SEPTEMBER, 1893

Rochester, N. Y.

Washburn-Crosby's Flour is used Exclusively at the World's Fair, Chicago, by the Wellington Catering Co. and the Original Vienna Model Bakery. Notice the DELICIOUS BREAD AND ROLLS served at these famous Bakeries. Write WASHBURN-CROSBY CO., Minneapolis, Minn. For World's Fair Souvenir Booklet FREE.

) HE THEM"
D. D.
'S BALLOT OF TO-DAY
My!"
"Fleur de Lis"

Figure 109. The first advertisement by a flour manufacturer addressed to the ultimate consumer. The first Washburn-Crosby periodical advertisement intended for the trade appeared in 1884 in the *Northwestern Miller.* Previously millers limited themselves to calendars and other occasional advertisements.

5-pound packages were sold as 100-pounds sacks, to dispose of but 5 per cent as much flour.

One indication of the growth of a national market was the 1899 decision of the Washburn-Crosby Co. to concentrate on a single top-brand flour, the "Gold Medal," which had received its name for the premium it won at the 1880 Cincinnati Milling Exposition. Previously, different brands had been sold in various parts of the country. In 1907 the famous slogan "Eventually – why not now?" was first used, while 1921 marked the appearance of Betty Crocker, that synthetic and sympathetic friend and guide of housewives all over the country.

Another phase of the growing interest of millers in the individual consumer, and in catering to and indeed cultivating his tastes, was the growth of the breakfast-food industry. In the 1840's and 1850's the market for breakfast cereals was almost confined to the foreign-born of Scotch and Irish descent, and was satisfied by imports of oatmeal. When American manufacture was extensively begun by Ferdinand Schumacher, he hit upon the idea of rolling the groats, reducing the time of home preparation from many hours to fifteen minutes. About 1883 corn flakes made their appearance, and over the following decades a whole new branch of food manufacture opened up. Millers at first were loath to enter the new field and feuded with those who did, who in turn often advertised their cereals as health foods, superior to ordinary mill products. In time millers saw the light, and thereby gained a market for milled products whose principal qualities of taste and satisfaction were those added in the course of manufacture, and whose consumption was linked to the continually increasing use of milk and sugar.

It was not until after 1900 that the expansion of large-scale baking opened up a constantly growing demand for types of flour quite different from those used in the home, flours adapted to high-speed mechanical mixers and to quick, absolutely dependable fermentation. Today approximately three fifths of the call for American flour comes from bakeries, while another one sixth arises from institutions and from industrial users, leaving about one fourth of the demand as the share of the home. From about 1900, as this market began to grow, millers took to calling second-grade flours, formerly "bakers," by the new name of "clears." The modern baker has little use for nondescript flours. Millers, in fact, were increasingly asked to build flours to precise bakery specifications where an excess of otherwise good qualities was just as undesirable as a deficiency: for satisfactory bread an unusually strong flour would make it necessary to change formulas and procedures. The millers also found themselves dealing with highly price-conscious purchasers, driven by competition and familiar with every known factor in good bread making and therefore able to choose a number of ways of reaching a desired result. As a consequence wheat blending began to play a more important part in American milling. It never, however, became the complex art practiced by English millers.

Simultaneously with these changes in markets, the American milling industry had to accommodate itself to local and international changes in wheat supplies. The hard-spring-wheat millers of the Northwest had always been contemptuous of St. Louis soft-winter-wheat flour; but from modest beginnings in the 70's a dangerous competitor to their vaunted hard spring wheat, in the shape of Turkey hard red winter wheat, began to spread over a vast territory to the west and south of the soft-winter-wheat area. German Mennonites in thousands had left South Russia as a hundred-year immunity from military service granted by Catherine the Great was about to expire, and had settled on a 200,000-acre tract in central Kansas, bringing with them 200 bushels of Turkey wheat. In 1860 less than 10,000 acres in Kansas had been sown to wheat, practically all of spring habit, although small amounts of soft winter wheat were grown in the extreme east. By 1878 with her 32 million bushel crop, over 80 per cent of hard winter type, Kansas began to be a powerful factor in the wheat and flour market. Nor was Kansas alone; the area open to the hard winter wheat has steadily expanded to the south and west. By 1919 it was sown on nearly one third of the wheat acreage of the country, more than was occupied by any other variety, and by 1924 on over two fifths of the acreage. Today, except in unusual years, twice as much hard winter wheat is harvested in the United States as spring wheat, and it occasionally happens that over half of all our wheat is of this kind. Figure 110 shows the approximate present-day limits of the American hard-winter-wheat area in relation to the areas covered by other types of wheat.

Like spring wheat before it, hard winter wheat was not favored at first and brought from 10 to 15 cents a bushel less than even soft wheat. It usually contains only 10–12 per cent of protein, as compared to 13–14 per cent for spring wheats; but it gives a greater yield by several bushels an acre, largely because it fits into crop-rotation patterns better than wheats raised farther north; and it is an excellent mixing wheat. Before it was accepted on its own account, its flour was often passed off as having been made from other wheats, as was wittily suggested by the cartoon of Figure 111, from the 1900 *American Miller*. In the late 90's, however, St. Louis turned more intensively to the milling of hard winter wheat in its own right, when soft-winter-wheat milling began to disperse and to trend eastward, since a good part of the crop was on the other side of the Mississippi.

Kansas City, however, was nearer to the hard-winter-wheat crop and therefore was able to outstrip St. Louis in the early 1900's. The Standard Milling Co. was the first of the large milling combinations to locate in Kansas City, in 1906. Her growth was not spectacular until after the First World War; but she has steadily forged ahead since, until in recent years she has

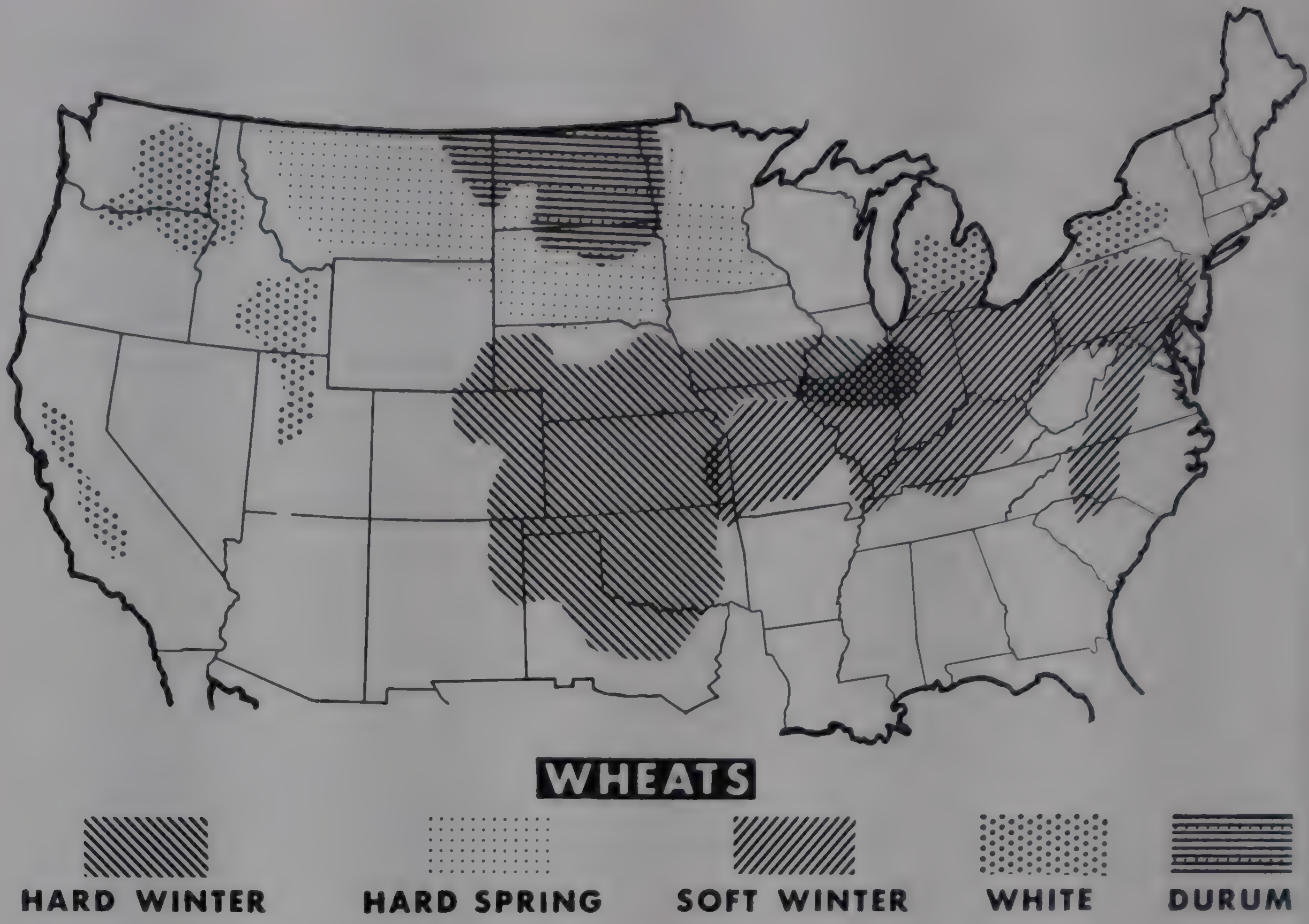

WHEATS
HARD WINTER
HARD SPRING
SOFT WINTER
WHITE
DURUM

Figure 110. Map of the principal United States wheat areas, as of 1946. No account is taken of competing crops. The great Corn Belt, for example, spreads across much of the soft-winter-wheat area, as also the northeastern corner of the area in which hard winter wheat is grown.

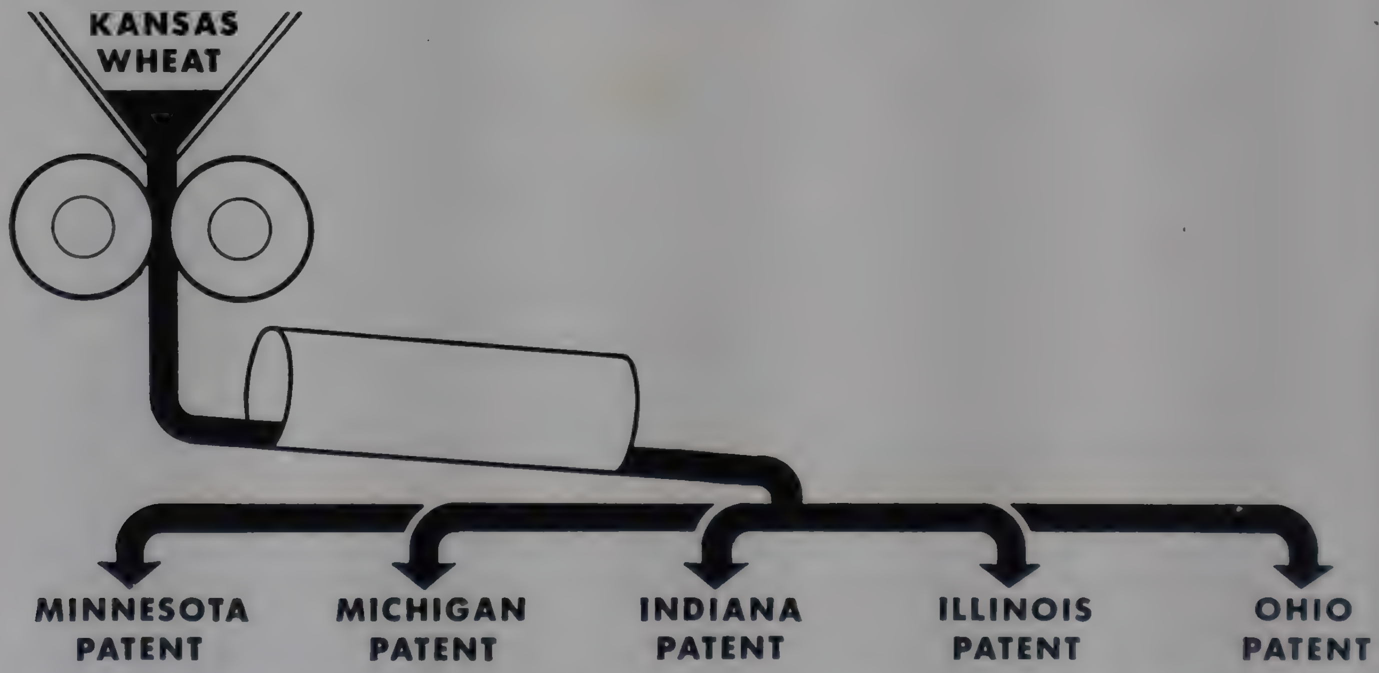

KANSAS WHEAT
MINNESOTA PATENT
MICHIGAN PATENT
INDIANA PATENT
ILLINOIS PATENT
OHIO PATENT

Figure 111. A cartoon from the 1900 *American Miller*, entitled "A Modern Flow Sheet," which comments on the contemporary mislabeling of flour made from hard winter wheat.

usually stood ahead of Minneapolis and second only to Buffalo, which has been the country's principal milling center since 1930. If the mills of the hard-winter-wheat section of the Southwest are regarded as a unit, however, they produce far more flour than those in any other part of the country; large mills are widely dispersed throughout Kansas and Texas, and to a lesser degree in Oklahoma and Nebraska. From 1921 the Southwest was producing more wheat than the Northwest.

Durum is another recently introduced type. This is a 14-chromosome, extremely hard wheat with a high protein content, which is used extensively for macaroni and other pastes and is occasionally mixed with soft wheats to make bread flour. It also got a bad reputation when it was first tried in this country. As Nicaragua wheat, durum was counted a failure in Texas in 1879–1882; it could not be ground satisfactorily on millstones unless it was tempered by wetting. It was also tried in Canada and our Northwest by Russian settlers who insisted on growing wheats that had done well in their native land, and under the name of goose wheat was universally excoriated by millers. The fiery W. C. Edgar of the *Northwestern Miller* called it an "agricultural nuisance," "part bread and part stone." In 1898, however, Mark Carleton of the Department of Agriculture was sent to Russia to search out drought-resistant wheats for planting on our high western plains; he came back with several varieties of durum and an enthusiastic conviction of their merits, which time bore out. In spite of continued grave warnings, about 75,000 bushels were harvested in 1901, a figure which had mounted to over 50 million bushels by 1906. Though durum production has fluctuated widely since that time, it has averaged over 40 million bushels a year since 1919. As shown on Figure 110, durum has taken over much land formerly planted to spring wheat, especially in North Dakota. But as bread wheats have been improved in rust resistance and yield, they have been able to regain considerable acreage formerly lost to durum.

About 1900, soft white wheats of the *compactum* type began to be grown on a large scale in our Pacific Northwest. These wheats are especially useful for the making of noodles, but they are also employed to make crackers, biscuits, and pastry, and even in general-purpose family flours, especially when they have been mixed with harder wheats like the durum grown in Montana. In more normal times in the 20's, our Pacific exports of these wheats averaged 20 million bushels; some of our largest mills are located in the Far Northwest. A fair amount of soft white wheat is grown in Michigan and Upper New York. The white wheats of California are of the hard variety; her exports to Europe became important after the Civil War, and in 1888, 34 million bushels left the state. In recent years, however, the California crop has declined in importance. To complete the picture of American wheats, it should be added that the soft-red-winter-wheat area

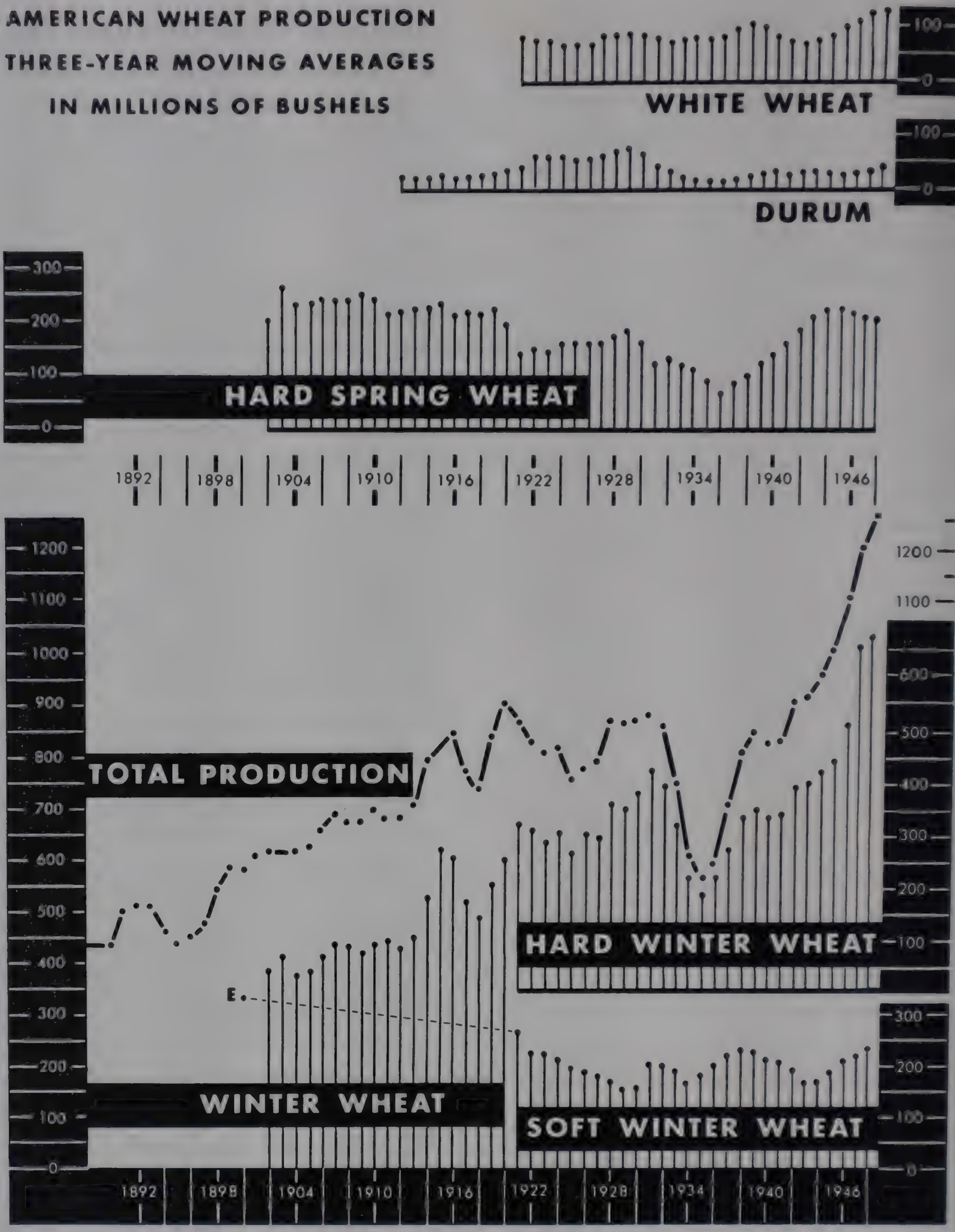


Figure 112. Three-year running averages of American wheat production, 1889–1948, and of the types distinguished in Department of Agriculture statistics. E marks an estimate of the soft-winter-wheat crop for 1900.

shown on the map still contains about one fourth of our total wheat acreage, or about as much as today is given over to spring wheat.

As for the total quantity of wheat produced, the 1866 American crop was the last to fall below 200 million bushels. From then on it climbed rapidly until it topped 700 million bushels in 1901. Figure 112 shows the

American wheat crop from year to year since 1888, and its distribution since 1902 into the types of wheat distinguished by the Department of Agriculture's statistics. The average production for the decade before the First World War was about 670 million bushels; then came the great 1915 billion-bushel war crop. The yearly average for 1920–1929 was over 820 million bushels, and for the next ten years 740 million. There followed a succession of large crops, topped by the eight monster yields of 1944–1951, which together totaled more then 9,000 million bushels. The yearly average wheat production of the entire world since 1935 has been about 5,730 million bushels, so that the United States over these years has contributed about 21 per cent of the world's average yield. Although western Europe normally grows 30 per cent of the world's wheat, that region, including the United Kingdom, requires over three fourths of the world's export surplus.

A powerful factor in bringing about increases in production was the constant improvement of wheat varieties to permit growth under greater climatic extremes, to make the plant more resistant to infestations, and to improve yields, ease of harvesting, millability, and the baking quality of the flours produced. We cannot follow the many changes whereby old wheats gave place to new – from Fife to Bluestem in the 80's among those of spring habit, and from the latter to the more famous Marquis about 1912 in this country, and on to Thatcher in 1934; or from Turkey among the hard winter wheats to Blackhull in 1917 and Tenmarq later. The life expectancy of a modern wheat variety is shorter than that of the farmers who plant it.

B. W. Snow has demonstrated that, contrary to the prevailing opinion, the producing capacity of American farmlands has actually been greatly increased since 1870, thanks to improved seeds and better farming methods. This fact has been obscured because we have been passing through a long period in which climatic factors have tended to decrease yields. When the average bushel yield per acre of wheat for each decade is corrected to account for climatic variations, the following index numbers of potential yield are obtained:

Decades	*Yield*	*Climatic Factor*	*Potential Yield*	*Index Number*
1870–79	12.3	91.9	13.4	100
1880–89	12.0	85.3	14.2	106
1890–99	13.2	80.9	16.3	122
1900–09	14.1	79.2	17.8	133
1910–19	14.6	77.2	18.9	141
1920–29	14.2	74.3	19.1	143
1930–36	13.0	61.9	21.0	157

Canada was an important wheat producer even before Saunders developed the Marquis variety of spring wheat there about 1907 – by 1901 her

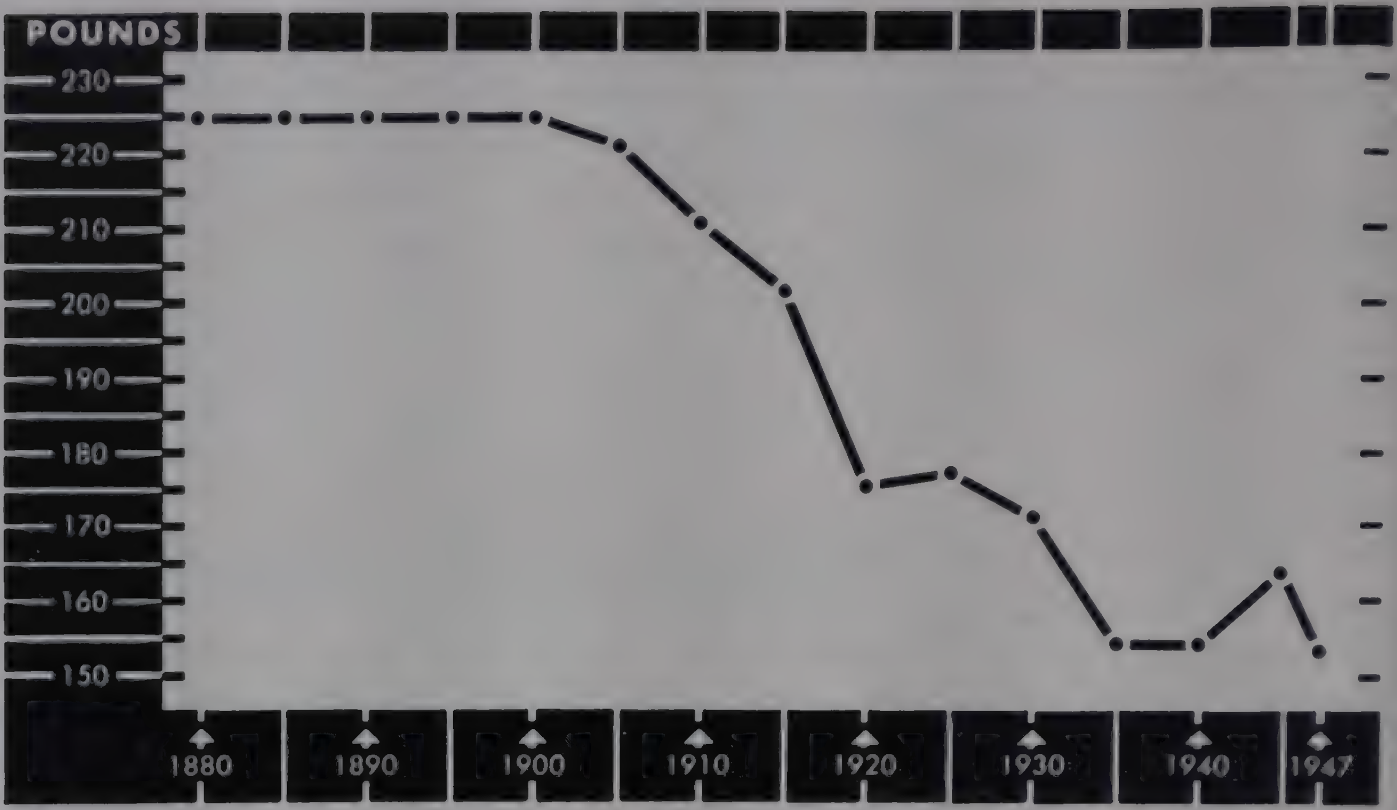


Figure 113. Twentieth-century decline in American per-capita flour consumption. Based on studies made by the Food Research Institute of Stanford University and by the Department of Agriculture.

production was already 84 million bushels, as compared with 88 million for Minnesota—but this hardy, early-ripening wheat greatly extended her area of production. It has been stated that Marquis added $75 million to the value of Canadian farm properties. The expansion of wheat-growing on Canada's prairies made her the greatest outside source of wheat for Europe's millions. Though Canada's production normally ranges from about one third to one half that of the United States, over the entire period from 1923 to 1946 her total exports of wheat were more than three times ours. From 1933 to the close of the Second World War, thanks mainly to her favored trade with the United Kingdom, Canada's flour exports were also greater than ours.

What was occurring in Canada was also taking place in the Argentine and Australia in the period before World War II. Since 1923 Argentina's exports of wheat have almost invariably surpassed ours, in recent years many times over, although her total production over the last few years has been only about one-half that of the United States. Since 1930, but not including the postwar period, Australia has also normally exported far more wheat than the United States, although her total crop has averaged less than one-quarter ours. The export surplus in these countries indicates the relative smallness of their domestic market as compared with ours, and largely for the same reason neither the Argentine nor Australia has developed a flour industry of a magnitude comparable to ours.

With constantly increasing supplies of wheat at home, and under the stress of growing competition, no longer mitigated in normal times by an expanding European market, the American miller was sorely beset. To add to all his other troubles, American per-capita flour consumption, which had been in a slow decline since about 1902, took an alarming drop during the First World War, until by about 1935 the average American was consuming only a little over two-thirds as much flour as at the beginning of the century (Figure 113). There were many reasons for this remarkable dietary change. Among them are increased consumption of milk, vegetables, and sugar, and the fact that commercial bakers use from 17 to 19 pounds of nonflour and nonwater ingredients as compared with the 5 pounds of former days; shorter hours of work and the spread of less muscular forms of activity resulting from urbanization and the substitution of machines for human labor; changed ideals of the human figure, together with the ending of the century of calories in favor of the era of vitamins; the emergence of new life patterns following upon the spread of the automobile; less wastage in the use of flour and of bread, including the gains from better packaging and mechanical slicing. Over the last fifty years, in fact, almost no factor has worked in the direction of increasing flour consumption. It will probably be of little effect in stemming the tide that American millers in 1940 began to enrich their flours with vitamins, although enriched white bread now contains all the protective vitamin qualities of the wheat berry in more digestible form than they can be obtained in dark breads.

In the face of this accumulation of problems, many merchant millers went out of business entirely, while others combined resources to make larger and, it was hoped, more efficient units. For the period from 1899 to 1947 we have comparable data on the number of mills. After a rise to 11,691 establishments in the enumeration taken in 1909 (the so-called Census of 1910), the number of merchant mills dropped until it reached a low of 1,243 in 1947, at the very peak of post-World War II production. Over the entire period from 1909 to 1947, the rate of decline has averaged a little under one mill in twenty for each year; during the period from 1919 to 1933, when the drop was especially severe, the rate of decline averaged about one mill in nine for every year.

Although we had less than one-eighth as many merchant mills in 1947 as in 1914, the total production of all merchant mills in service remained essentially unchanged. In only two of the years between 1914 and 1939 for which the flour production is recorded in Figure 114 did the annual figure fall below 102 million or rise above 120 million barrels (a barrel of flour weighs 196 pounds); the average production was 113 million barrels. But whereas the average 1914 merchant mill produced about 30 barrels daily, that of 1939 averaged about 144 barrels. For 1947 this figure had more than doubled, on account of postwar requirements. Though the

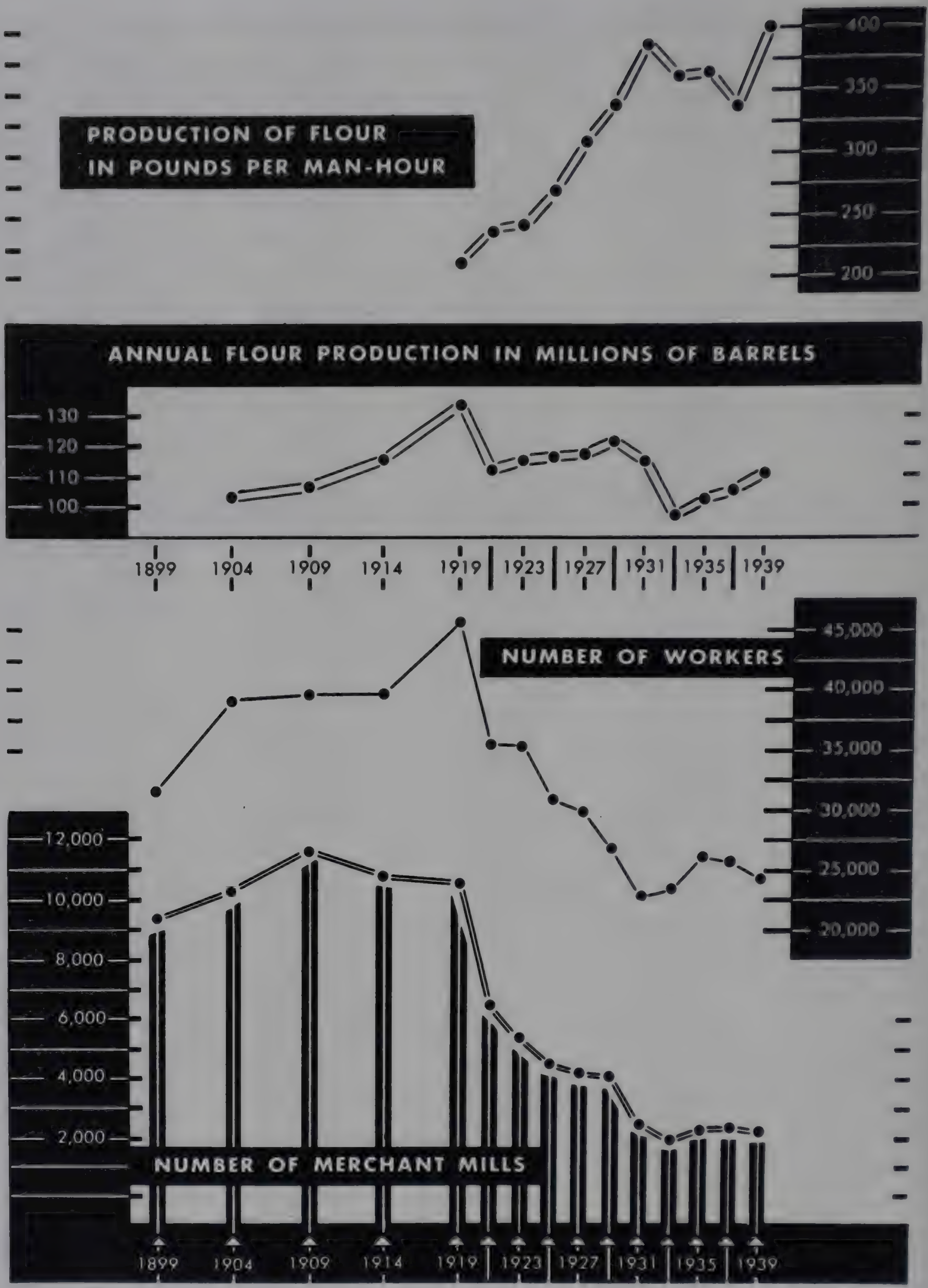


Figure 114. Data concerning American merchant mills, 1899–1939, based on Census figures. In the war and postwar period flour production rose to a maximum in 1947 of well over 300 million cwt. (about 260,000 barrels) without the building of new mills; this figure gives some idea of the normal excess capacity of the industry.

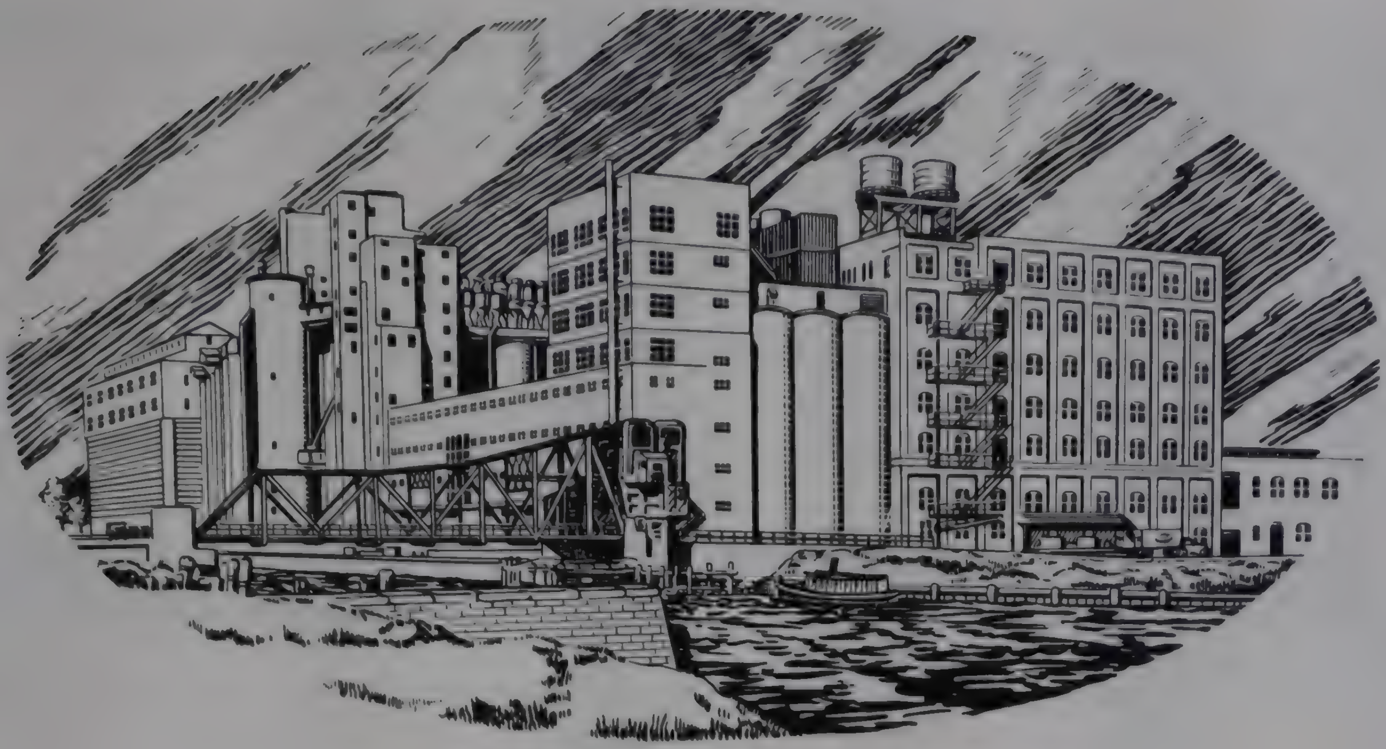
average number of workers per establishment rose from 4.3 to 11.6 between 1914 and 1939, the total number of workers employed dropped from 45,481 to 24,771. For the unusual year 1947 it was 39,458, and American mills averaged a production rate at 111 per cent of their five-day week capacity. By 1950 they were at an 89 per cent capacity level, which was still considerably above prewar figures.

When account is taken of the average number of hours worked – 50.6 per week in 1919 and 42.3 in 1939 – the hourly production of flour per worker rose from 214 pounds in 1914 to 400 pounds in 1939. This figure had been increased to about 430 pounds by 1947. On the basis of an annual per-capita flour consumption of 154 pounds, an American miller in 1939 needed but 23 minutes to make all the flour the average American would consume in a whole year. This figure applies to the industry as a whole; an efficient large company would easily better it. In 1947, for example, when General Mills had 12,439 employees in all branches of work, plant capacity was 456 pounds of flour per worker-hour, so that the average American's yearly consumption could be met in twenty minutes. In addition the plants had a formula-feed capacity of 460 pounds per worker-hour and one for package foods of 5.2 pounds, and a great many other products were manufactured as well.

Though these figures are striking, the increase in importance of the large mill is much greater than any production figures or averages could show. Mill capacity is traditionally given on the basis of a twenty-four-hour day for a three-hundred-day year. In the busy season, from September through November, as the new crop comes in, mills may work to capacity; but over the course of a year the grind of most mills falls far short of the maximum. In 1920 the Federal Trade Commission estimated (probably with some exaggeration) that our mill capacity was two and a half times our largest yearly production. In pursuit of the economy which accompanies size in flour milling, if efficient planning is assiduously applied, some of our mills have grown astoundingly, ranging up to a maximum of 37,000 cwt. (about 20,000 barrels) capacity per day (Oval, Chapter XVIII). A single mill of this size working full time could easily satisfy all the flour needs of New York, a city of eight millions. We have about fourteen mills with a daily capacity of at least 10,000 cwt., having an aggregate capacity of something like 210,000 cwt. Since our daily consumption amounts to about 640,000 cwt., these mills alone by working around the clock could satisfy about one third of our entire domestic needs. Our fewer than two hundred mills with capacities of over 2,000 cwt. a day could have given us all the flour we currently use, with about 200,000 cwt. a day to spare.

Nor is this all. Managerial responsibility has become increasingly concentrated as the scope of operations has enlarged. Today a single firm – General Mills, Inc. – could supply about 22 per cent of our total flour needs; five firms could supply over 50 per cent; twelve about 75 per cent. In an effort to render themselves invulnerable to the vagaries of crops and conditions in any part of the country, and to place themselves in more advantageous relations to markets and sources of supply, large mill combinations have set up plants in many parts of the country: General Mills has flour mills at nineteen points, besides feed plants, package-food plants, grain elevators, farm-service stores, sales offices, and centers of other activities scattered all over the country (Figure 128).

Nor does even this complete the story. These large mills have come to realize the necessity of large research staffs devoted, on the one hand, to improving milling processes and, on the other, to diversifying the products of the enterprise; and they have increasingly been led to look upon themselves as public-service organizations standing in an entirely different relation to the ordinary citizen, and to the government, from that envisioned by the miller of even a generation ago. It is to a description of the contemporary integrated mill that we now turn — the mill, that is, which is integrated not only in its internal operations but in relation to a dynamic and democratic economic system as a whole.



CHAPTER XVIII

The Modern Mill and Its Flour

> The fact that a mill is automatic is one reason why it cannot have automatons to run it.
>
> —Editorial, *Northwestern Miller* (1883)

In 1887 an anonymous writer in the *Northwestern Miller* set forth as "the four commandments of a mill," "You must make quantity, quality, percentage, and yield." Large mills best live up to these commandments, and thereby are in line for the rewards that follow their faithful observance. The first commandment, in fact, is to *be* large. Because milling is an industry in which the raw material is processed with relatively little addition to its value, millers during the past century have striven for greater quantity of output to increase the net difference between what they must pay for wheat and other raw materials and what they will get for the finished products. This figure, the difference between the cost of all raw materials used in production, including power, and the value of the goods produced, is called "value added by manufacture." The labor involved in manufacture is not included in raw-material costs, since it is one of the factors utilized to upgrade the raw materials.

Figure 115 charts the percentage of value added by manufacture in

Chapter head oval. The world's largest mill, that of General Mills, Inc., at Buffalo, New York, with a daily flour capacity of 37,000 cwt.

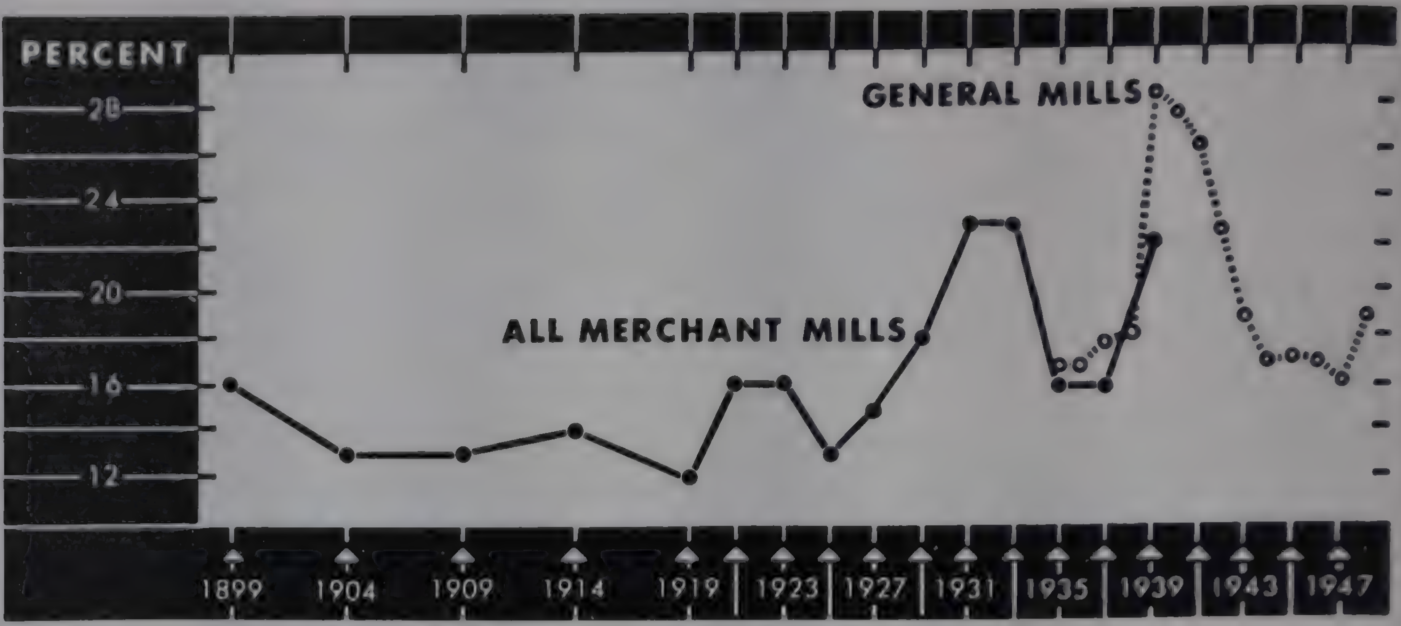


Figure 115. Percentage of value added by manufacture through the operations of all merchant mills, 1899–1939, and by General Mills, Inc., 1935–1948.

merchant-milling operations from 1899 to 1939, a period for which the records are comparable. That the greater part of the increase in the value of the finished product shown here was due to economies arising from an increase in the scale of operations is suggested by comparable 1935–1939 figures for General Mills, Inc., the largest producer in the milling industry. Later data from the same source hint that the value added in the smaller mills has declined somewhat since 1939, although it probably still stands well above the average figure for the period up to 1919.

Large-scale milling makes it easier to obey the other commandments of quality, yield, and percentage. Quality depends first on the natural attributes of the wheat milled and thereafter on informed control of production. A large mill is in a better position to buy the wheats that will make the best possible mill mix, and handles enough of most substocks to justify adding machines to treat them as they require. It can afford to support the research in field and mill that today is so necessary to advancement. As for yield, in former days it was almost entirely a matter of flour produced, while percentage depended on the proportion of high-grade flour in the total yield. Today yield may include many merchantable items besides flour, and the large mill is in the best position to produce a great diversity of these and distribute them to the best economic advantage. Since 1922, except when war regulations required larger extractions, American millers have used very close to 4.6 bushels of wheat on the average to make a barrel of flour. Thus the absolute yield of flour probably has not been increased greatly over yields of the best millstone days, but there is less bran in the flour and less flour in the bran, on the one hand, while percentage and quality of the best grades have been improved.

Current gains in the quality of flour are not matters of surmise; they are proved in certain respects by simple though delicate measurements of the percentage of ash remaining when stocks are burned under laboratory conditions. Since pure endosperm yields about 0.32 per cent ash and pure bran about 5.85 per cent, the ash content of a flour specimen is a measure of its bran contamination. In 1883 three high-grade Hungarian flours were tested in England and found to have ash contents of 0.37, 0.37, and 0.40, giving an average bran contamination of 1.1 per cent; two American patent flours tested at the same time yielded ash of 0.43 and 0.60, or a contamination of 2 per cent for the better of the two. But this standard was attained in only 18 per cent of the Hungarian output, while the American flours represented 40 per cent extraction and were far cheaper. Today it is not unusual for the better American mills to make a straight hard-wheat flour with an ash content of 0.44, very close to the 1883 figure for patent flour; "long" 90 per cent patents, containing 90 per cent of all the flour, with an ash content of 0.402; "standard" 75 per cent patents with an ash of 0.374; and "short" 50 per cent patents with an ash of 0.36.

It should be noted, however, that ash figures are not entirely sufficient as an index of quality: although soft winter wheat yields a low ash percentage, it does not make as good bread as hard wheats, since it contains less protein, of a quality not wholly suited to the fermentation process. It is nevertheless true that for flours with good bread protein quality, any increase in ash above about 0.465 per cent results in a rapid lowering of loaf volume.

American mills have also achieved great gains in the quantity of flours of the highest grade produced. In 1881 patent flours represented 60 per cent, in 1884 about two thirds, of a typical large American mill's output, under a loose system of grading. Today excellent long 90 per cent patents are attainable in most large mills.

The marketing of this high-grade flour, still the mainstay of the miller's business, presents serious problems. Most flour in quantity is sold at a fixed price for delivery at the call of the purchaser within a specified period – usually 120 days. And when the miller makes such a contract, he cannot be sure of the price he will be able to get for any low-grade flours and the large quantities of feed he must produce in the course of manufacturing the flour ordered. His business is initially complicated by the fact that his raw material varies seasonally and locally in quality and yield, so that the utmost attention must be paid to supplies; and the business is bedeviled also by continual changes in the price of wheats and of different grades of flours and feeds – changes that may throw otherwise well-conceived transactions into the loss column, especially when prices are closely figured. A large mill can meet these difficulties more successfully than a small one. It can afford to keep closer watch over its operations, since the expense is spread over more transactions. It is more certain of a continuous flow of orders and can cultivate markets that tend to balance each other. It can spend money to develop new outlets for its by-products. And it can make more effective use of the futures market for "hedging" – by purchasing wheat for future delivery, for example, to balance its own future commitments as to flour deliveries, and by selling these futures as the flour deliveries mature.

The large mill can also pay more attention to other products than flour. It can afford to make more searching separations in the cleaning department, recovering for separate treatment and sale seeds of special value that may be mixed with the wheat, or even setting up effluent recovery systems to separate what is of value from the water used in washing, as is done in some English and a few American mills. The separated germ can be packaged and sold at a much higher price than the feeds to which it would otherwise be routed. Breakfast-food plants can add their support to regular milling operations. The large mill can market chemicals and other materials of industrial value derived from wheat or even from other materials. It may discover surprisingly varied outlets for the engineering and research staffs now so indispensable for satisfactory large-scale milling.

It is these large enterprises that have made milling an engineering technique, in place of the art or craft it was less than a century ago, and today they set the pace in the industry, determining processes, policies, and public relations. In an analysis of the nature and problems of milling today the small mill can be disregarded, in spite of its often interesting problems and headaches. Not that even very small mills are hard to find – for example, one small miller-baker located on upper Broadway in the borough of Manhattan, New York City, ships bread by air mail as far as the West Coast. There are other active small mills in the immediate vicinity of New York City; but the really typical American mills of today have a daily capacity of many thousands of hundredweights.

The layman visitor to a large flour mill invariably leaves in a daze. He expects machinery, lots of it, and is ready to be puzzled, but not quite so mystifyingly as he is. So little appears to be going on, and so few people are involved. He looks over an entire floor of roller assemblies, all externally alike (Figure 129), with nothing visibly in motion if the power belts are enclosed, and perhaps with no human being in sight except his guide. Only a low hum and a sweetish odor hint that work is going forward – there is no outside evidence of the many delicate varieties of grinding being accomplished inside the machines. Another floor, perhaps also deserted, is covered with immense, solemnly twisting, cratelike boxes – the sifters – served by a forest of chutes from above and below; once more there is nothing to indicate the diverse separations being achieved inside the boxes. On yet another floor stand the purifiers, silent, monotonous, and alone (Figure 130); through their windows the visitor can watch the enigmatic dance of the lighter particles over the vibrating sieves. Up near the roof is row on row of dust collectors with their tubes arranged like the spokes of a wheel, turning and resting, one step at a time. Here and there the visitor will meet a miller, but only in the packing room will anyone seem to be doing much to further production. Almost everywhere overhead and under the machines he will see chutes passing from floor to floor. Many other conveyers running horizontally from machine to machine or inside machines will escape his notice, and he may miss even the elevators that carry stock to upper floors. There will be little to indicate the plan according to which work is being carried on, what system governs the multitude of machines, why they are arranged as they are.

Almost the only way for even a miller to gain more than a vague impression of a modern flour mill is by a study of its flow sheet—that logical diagram of the breaks and purifications and separations, the processes and perambulations of stock, that millers found indispensable almost as soon as roller milling began to be pursued in good earnest in the 80's. We have already discussed two very different early flow sheets (Figures 99 and 101). From 1883 on, such diagrams began to appear regularly in the *American Miller*. Over the years its readers submitted literally hundreds of flow sheets for the not always kindly criticism of their "dusty brethren," as for long they liked to call each other. No error in grinding or in purifier separations, in mesh of bolting cloth or in routing, in too few or too many breaks or reductions, was allowed to pass unchallenged; countless differences of opinion were aired, and slowly over the years the standards and customs of modern American milling emerged.

The flow sheet makes clear the interconnection of activities to produce a planned result. From the entry of the grain to the departure of the flour and feed, each operation of a soundly organized mill depends on everything that precedes and follows. Though a complete flow sheet for a large modern mill would discourage all but the most enthusiastic of amateurs, the sequence of modern milling processes can be indicated and salient parts of a typical flow sheet analyzed in some detail without asking too much of the nontechnical reader. Figure 116 is a highly simplified diagram of everything that happens in a modern mill from the entry of the wheat into the cleaning department to the production and packaging of the finished flours and feeds. Practically every heading in this diagram stands for a number of operations. We shall run rapidly through the entire procedure and put a little flesh on the skeleton chart in the course of indicating ways in which twentieth-century milling differs from the practices we have already described. We shall follow the activity from grain elevators to packaging.

Where land and construction costs permit, the storage elevators serving a large mill should be able to hold a considerable supply of grain, so that wheats can be purchased at harvest time, if the price is right, when there is

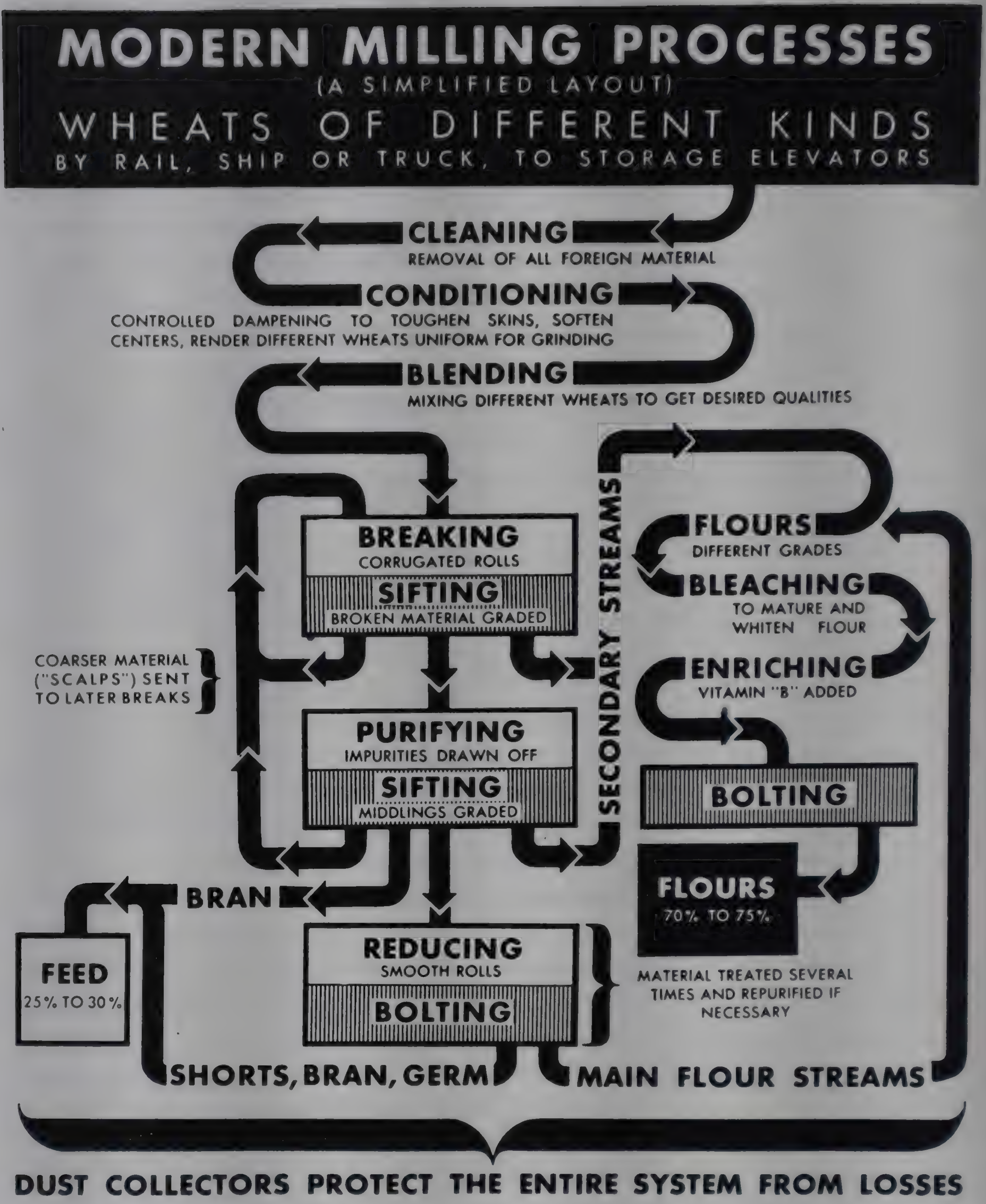

MODERN MILLING PROCESSES
(A SIMPLIFIED LAYOUT)
WHEATS OF DIFFERENT KINDS
BY RAIL, SHIP OR TRUCK, TO STORAGE ELEVATORS
CLEANING
REMOVAL OF ALL FOREIGN MATERIAL
CONDITIONING
CONTROLLED DAMPENING TO TOUGHEN SKINS, SOFTEN CENTERS, RENDER DIFFERENT WHEATS UNIFORM FOR GRINDING
BLENDING
MIXING DIFFERENT WHEATS TO GET DESIRED QUALITIES
BREAKING
CORRUGATED ROLLS
SIFTING
BROKEN MATERIAL GRADED
COARSER MATERIAL ("SCALPS") SENT TO LATER BREAKS
PURIFYING
IMPURITIES DRAWN OFF
SIFTING
MIDDLINGS GRADED
SECONDARY STREAMS
FLOURS
DIFFERENT GRADES
BLEACHING
TO MATURE AND WHITEN FLOUR
ENRICHING
VITAMIN "B" ADDED
BOLTING
FLOURS
70% TO 75%
BRAN
FEED
25% TO 30%
REDUCING
SMOOTH ROLLS
BOLTING
MATERIAL TREATED SEVERAL TIMES AND REPURIFIED IF NECESSARY
SHORTS, BRAN, GERM
MAIN FLOUR STREAMS
DUST COLLECTORS PROTECT THE ENTIRE SYSTEM FROM LOSSES

Figure 116. Highly simplified flow chart of major modern milling operations from the entry of the wheat into the mill to the exit of the manufactured products. Each line of flow in the chart represents a number of mill streams, depending on the size of the mill.

a full range of choice. It will sometimes happen that a part of the wheat used can best be stored closer to the farms than to the mills, but in some instances today mill elevator capacity ranges from 70 to 275 days. For a 10,000-cwt. mill the annual grind is about 7 million bushels, so that ample trackage and unloading facilities must be provided; at the height of the delivery season such a mill may handle up to 100 cars of wheat a day, in addition to the cars needed to dispatch finished products. The grain is sampled and weighed on entering storage, and is given a rough preliminary cleaning by one or more receiving separators on entering or leaving the elevator section. These separators need not differ greatly from the old one shown in Figure 81, although they have been greatly improved in balance and drive. New machines like the ingenious "scalperator" shown in Figure 117 are also used, but no attempt is made to do thorough cleaning at this stage—high capacity is more important here.

The stock is thoroughly cleaned just before grinding, and by about 1910 the modern revolution in milling began to penetrate into this department. In a typical cleaning program for a large American mill, as diagramed in Figure 118, the wheat is given five aspirations, runs over two sets of magnets, is scoured twice and passes through a number of separators, besides undergoing an optional heating and two temperings; if necessary, it can also be washed and dried just before the tempering.

The aspirating is done in stages so that lower air velocities may be used, keeping small, good wheat from being lifted. After the impurities are lifted, the heaviest are dropped in an expansion chamber of the aspirator so that whatever is of value in them may be more easily recovered. Figure 119 shows two modern types of aspirator; in one a spreader conveyer assures an even flow of grain throughout the length of the machine, while the other

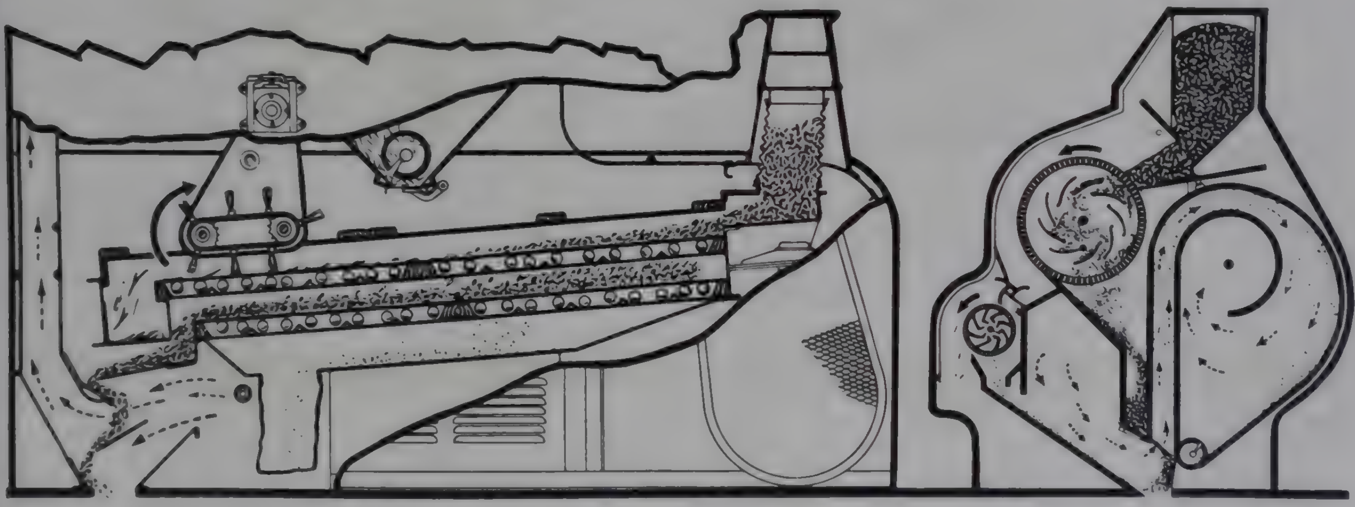


Figure 117. At the right, an improved receiving separator, the Carter "scalperator," in which the grain first falls through a squirrel-cage scalping reel, the larger roughage passing over the top of the reel for rescalping by the smaller reel. The aspirating leg and settling chamber at the right of the machine conform to present-day knowledge of air flow. At the left, an improved milling separator, the Carter "millerator," in which the sieves gyrate near the head of the machine and swing back and forth near the tail, their meshes being kept open by bouncing rubber balls. Brushes slowly moving over the surface of the top sieve near its tail retard the flow of material, preventing the tailing-over of good grain on the roughage.

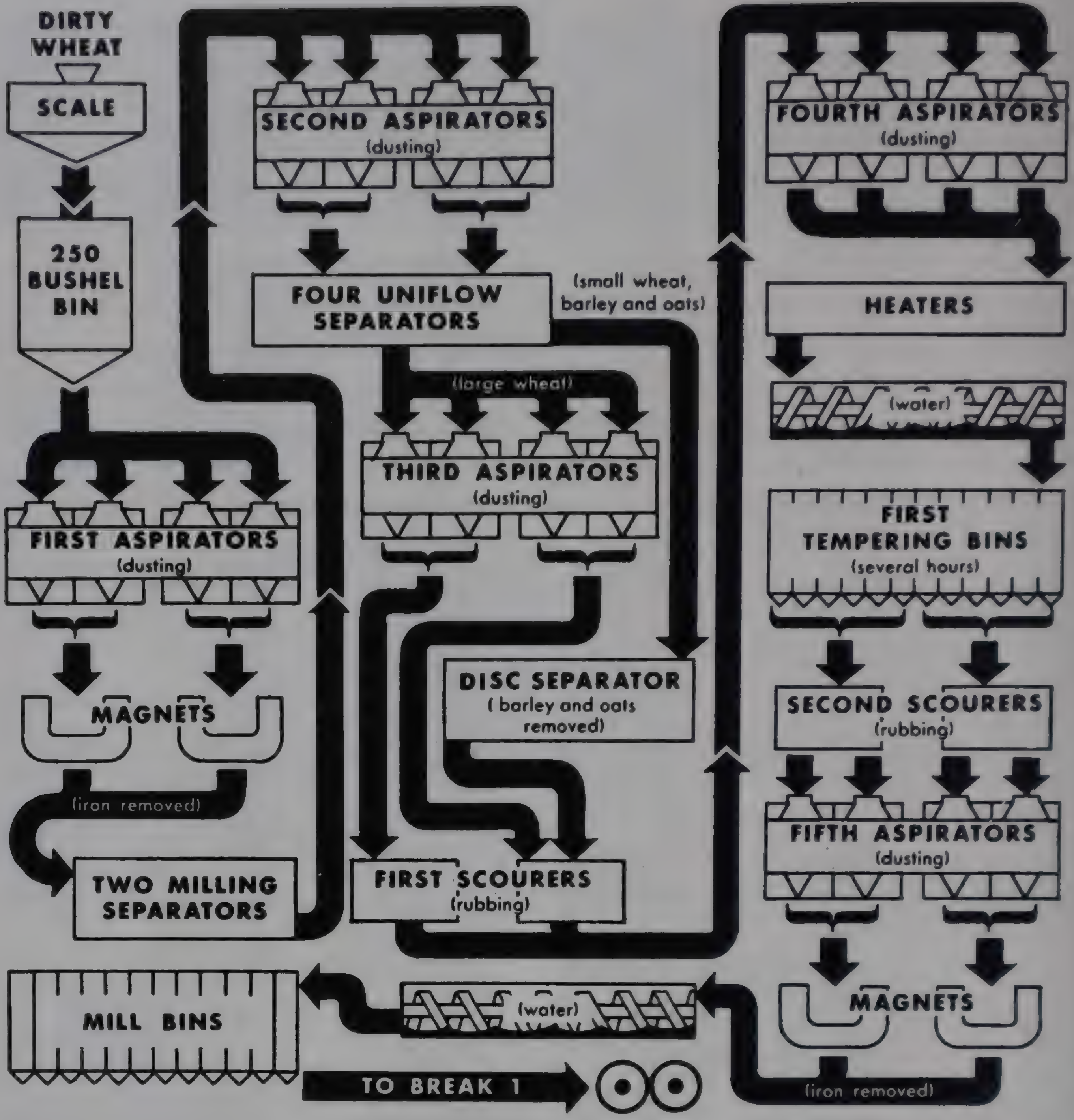

DIRTY WHEAT
SCALE
250 BUSHEL BIN
FIRST ASPIRATORS
(dusting)
MAGNETS
(iron removed)
TWO MILLING SEPARATORS
SECOND ASPIRATORS
(dusting)
FOUR UNIFLOW SEPARATORS
(small wheat, barley and oats)
(large wheat)
THIRD ASPIRATORS
(dusting)
DISC SEPARATOR
(barley and oats removed)
FIRST SCOURERS
(rubbing)
FOURTH ASPIRATORS
(dusting)
HEATERS
(water)
FIRST TEMPERING BINS
(several hours)
SECOND SCOURERS
(rubbing)
FIFTH ASPIRATORS
(dusting)
MAGNETS
(iron removed)
(water)
MILL BINS
TO BREAK 1

Figure 118. Cleaning program for a large mill, omitting dust-collector flow and program of treatment for materials separated from the main stock.

uses centrifugal force to spread the stock evenly in the path of the ascending air.

The milling separators used in large mills may be sieve machines not differing essentially from those used as receiving separators in mill elevators, although the sieves will be more finely meshed and will work under lower capacity; but machines utilizing new ideas are available, like the "milling scalper" of Figure 120 or the "millerator" of Figure 117. Two other separator operations are called for in the cleaning diagram. The "uniflow" is an improvement on the old *trieur* shown in Figure 82; it has an additional automatically adjusting conveyer under the apron to spread the grain evenly along the cylinder and to counteract its rolling tendency as the cylinder revolves. The disc separator as shown in Figure 121 is also a remarkably ingenious adaptation of *trieur* principles. Though disc separators are far superior to cylinder separators, many of the latter are still used on account of their lower initial cost.

Vertical or horizontal friction scourers not greatly different from the old smutter of Figure 81 are still found in many American mills, although the machine has been greatly improved in detail and the action is usually more gentle than was once the fashion. Machines with rotating brushes to scour the grain are also sometimes used, the stock being aspirated to rid it of the brushed-off material. Figure 122 shows an "in-suspension" scourer in which the grain is thrown horizontally through an air-swept space by propeller-like blades, without touching the casing; the cleaning is due to agitation in cross currents of air rather than to contact with metal or abrasive surfaces.

Although wheat washing, conditioning or tempering, and blending are more common in twentieth-century American mills than previously, no

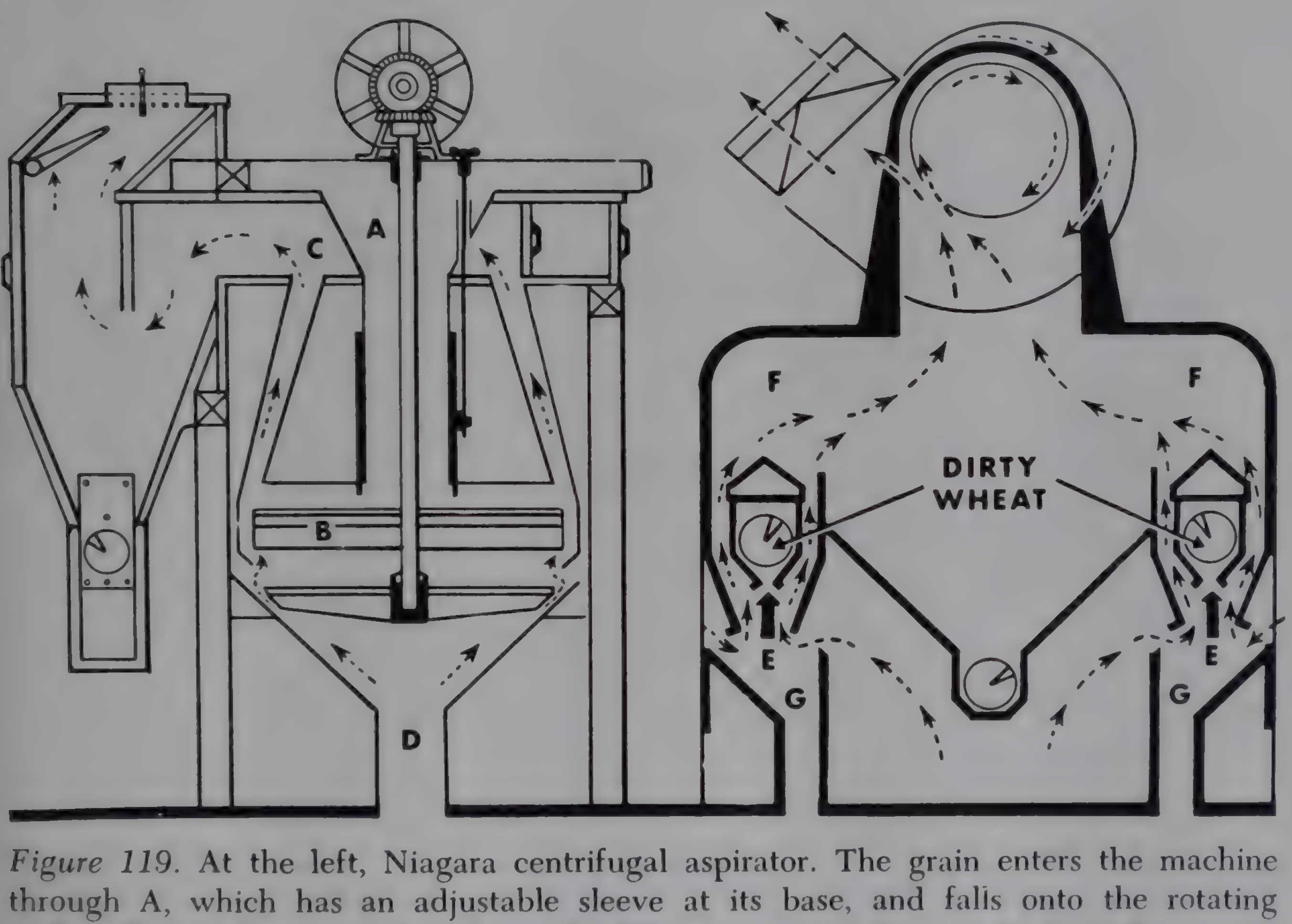


Figure 119. At the left, Niagara centrifugal aspirator. The grain enters the machine through A, which has an adjustable sleeve at its base, and falls onto the rotating surface B, which spreads it in the path of the air current (shown by dashed arrows). Light materials are carried by way of C to an expansion chamber fitted with an exit for lighter stuff and a conveyer for heavier, while the cleaned wheat leaves by way of D. At the right, double Superior aspirator in which the dirty wheat is spread on either side by a conveyer and falls over a barrier E, which divides it into two streams for aspiration. Light materials are carried by way of F to an expansion chamber with a conveyer, while the clean wheat leaves by way of G.

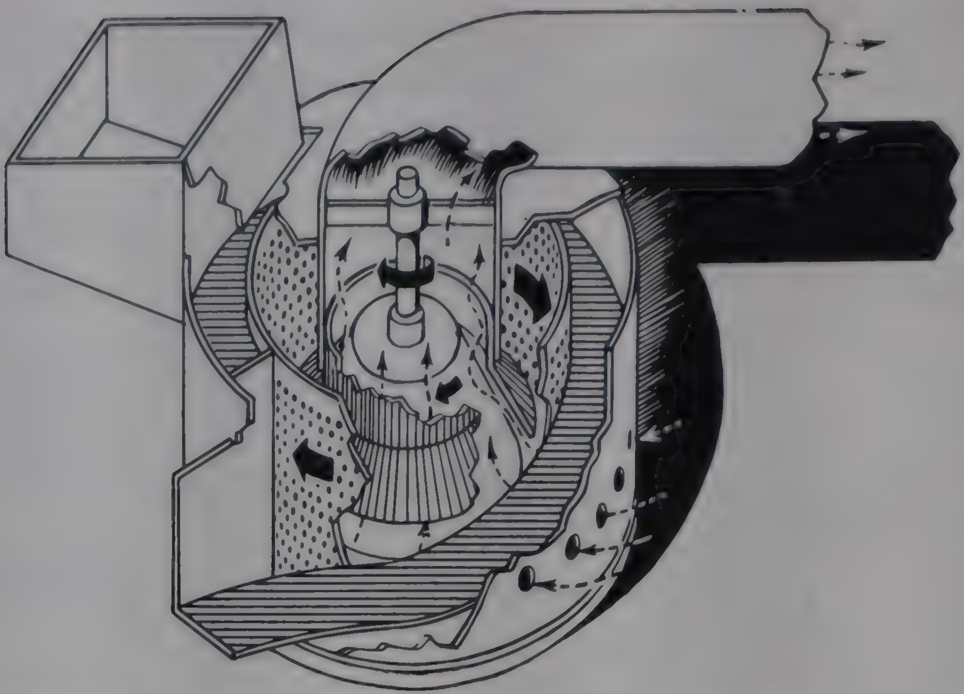


Figure 120. Haaky "milling scalper." Dirty grain passes from the hopper at the upper left onto a spiral chute which surrounds a slowly rotating cylinder pierced with holes. Roughage leaves the machine by way of the chute, while the grain falls through the holes onto a flared piece which freely surrounds the exit cylinder, through which a rising aspirating current leaves the machine. At the base of this cylinder a slowly rotating core distributes the grain in the path of the ascending air and keeps it in motion, while the flared piece automatically rises or falls according to the quantity of grain surrounding it.

novelties beyond those already discussed as typical of English mills have become general. In the field of wheat-washing, from about 1903, August Wolf was a pioneer in introducing European methods to American millers.

In the break and reduction sections roller assemblies have been greatly improved in almost every detail, to meet increasingly strict standards of economical, safe, completely controllable operation for mass production. Some American mills have introduced the rather common European method of dividing the wheat into plump berries and thin just before grinding begins, and of setting a special first break for each size. Of course, all roller assemblies are exhausted these days, to cool them and to free the chop from dust. In 1935, after several years of experimentation, Allis-Chalmers placed a "battery" type of roller assembly on the market, in which a number of double roller pairs set in line on a firm base are driven as a unit by a single integral electric motor (cf. Figure 129). Earlier efforts along this line had proved abortive in the absence of a suitable flexible coupling and satisfactory chain drives. An important feature of the Allis-Chalmers drive is the manner in which the slow roll of each pair of a double stand is chain-linked to the fast roll of the other pair (Figure 123).

One procedure emphasized by Figure 116 is the regrinding on later break rolls to which coarse materials from purifier sifters are submitted; also indicated is the repurifying of coarse materials from reduction-roll sifters. This does not mean that any materials retrace their steps; they are always sent farther on in the mill to machines set to give them a treatment adapted to their attributes. Stocks needing regrinding, for example, go to rolls with finer corrugations set closer together than those from which they came. It is here that large mills are most superior to small; as capacity increases, sequences of machines can be added to treat more finely differentiated grades of material.

The aim of modern milling is to produce middlings first, and only later, and even then only by degrees, to manufacture finished flour and bran. Too close grinding at the start reduces the endosperm to a powder of flour and bran. If the rollers are too far apart, too many hard-to-manage "chunks" are made, consisting mainly of bran, but with a little adhering endosperm. All stocks are carefully separated by sifters after each break: the coarsest material is *scalped* off for further treatment at the next break,

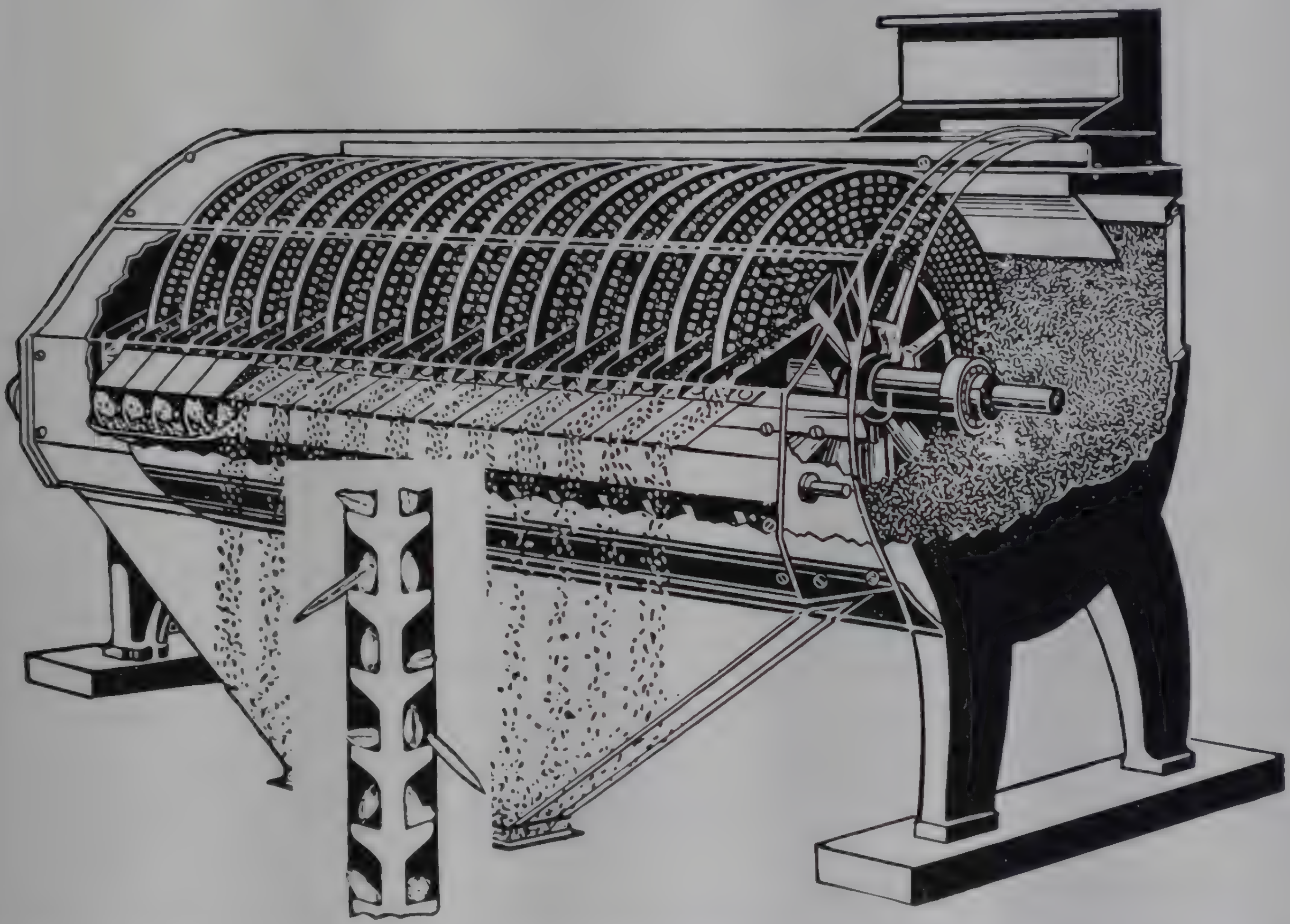


Figure 121. Carter disc separator. Grain mixed with other seeds enters the machine at one end, and a separation is effected by the indentations in the numerous rotating discs, as shown in the enlarged insert. According to the size and shape of the indentations, they will lift wheat itself or seeds either larger or smaller than wheat. Material not lifted is carried to the tail of the machine by the slanted spokes of the discs, while the material picked up by the indentations falls into chutes and out of the machine as the discs rotate. The separator is in effect a large number of *trieurs* set around a single axle.

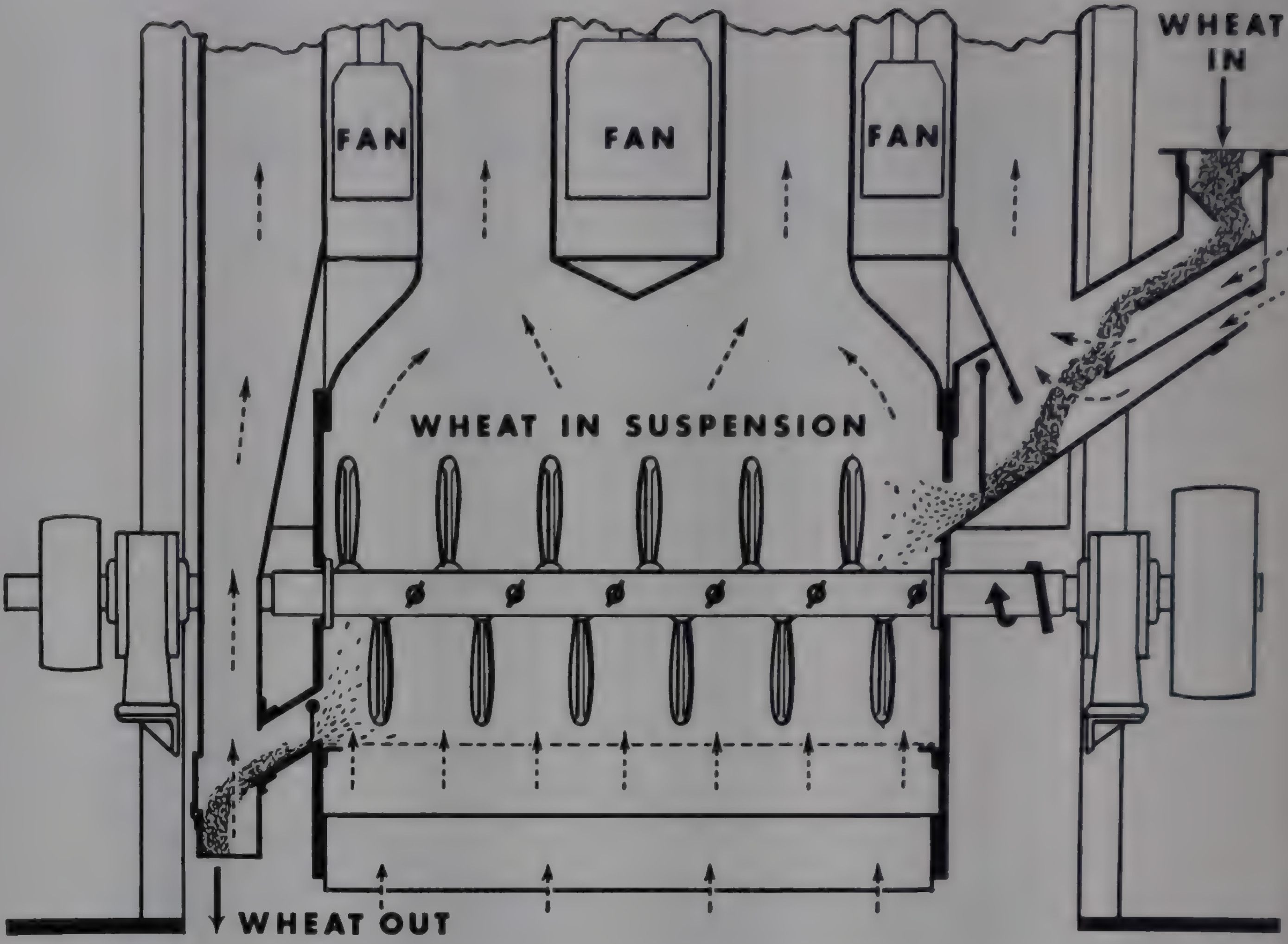

WHEAT IN
FAN
FAN
FAN
WHEAT IN SUSPENSION
WHEAT OUT

Figure 122. Eureka "in-suspension" scourer. After receiving a preliminary aspiration as it falls into the machine, the grain enters a chamber, exhausted by three fans; here a number of adjustable beaters of airplane-propeller type cause it to swirl about and out at the tail of the machine, so that it is thoroughly air-scoured without injury.

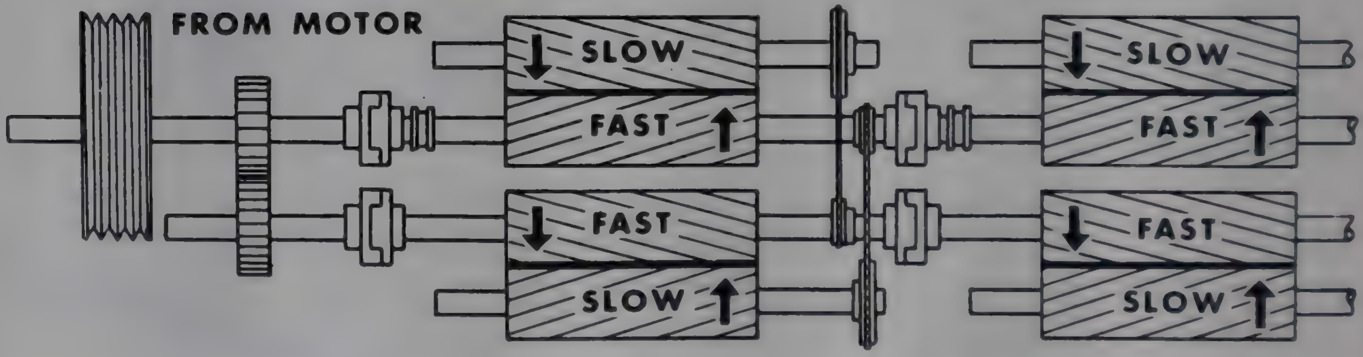

FROM MOTOR
SLOW
FAST
FAST
SLOW
SLOW
FAST
FAST
SLOW

Figure 123. How the slow and fast rolls of the Allis-Chalmers "battery" roller assembly are cross-linked. A texrope drive from the motor rotates the shaft of one fast roll of the first double assembly through a flexible coupling; the other fast roll of this assembly is driven by 1:1 gearing as shown. These fast rolls are shafted through flexible couplings to the fast rolls of the next double assembly, and each one drives the slow roll of the other pair through a chain.

or in the case of the last break by a bran duster; the intermediate stocks are *graded* so that they may be sent to the purifier best suited to them; the smaller flourlike material is *dusted* out. Break corrugations are chosen and the breaks and sifters are arranged "to balance the mill" – to provide each following machine with exactly enough of the proper stock for efficient functioning on its part and to maintain balance in other machines still farther on in the mill.

Thus the efficiency of the break section of a mill is accurately indicated by its success in holding down the quantities of flour produced in the early breaks. Figure 124 compares characteristic distributions of stock in an American five-break mill, an English four-break mill, and a Continental eight-break mill, with all percentages stated in terms of stock delivered to the first break. Here it will be seen that less break flour is made by the American five breaks than by either four or eight breaks. With an increase in the number of breaks, it is possible to effect a slightly larger total extraction of flour – being in fact the only method of accomplishing this in the modern mill as we know it. But this entails an equivalent increase in purifiers and reduction rolls, so that the small increase in flour does not justify the expense. This is especially true since there is no accompanying improvement in the average quality of the product; while a little more good flour can be made at the head of the mill, a little more poor flour must be made at the tail. Better quality is more likely to be obtained, after a certain point is reached, not by adding more machines but by improving those already in use or, indeed, by discovering totally new processes.

Today, most of the bolting in American mills is done by machines of the plansifter family, except near the tail of the mill, where centrifugals are often used. The plansifter, usually called simply "sifter" in this country, has been so improved in performance and changed in appearance, however, that novices would hardly recognize the old "low-head" machine as basically similar to the many varieties of "high-head" machine now in use (Figure 105). In suspension and balance, in ease of cleaning and replacement of sieves, and in many other ways, the fundamental invention of Haggenmacher, which still remains valid, has been improved by modern engineering science.

Following the American lead of the Washburn A mill in 1894 – the process had been used in England by 1886 – it has become customary over the last few decades to rebolt the flour just before packaging, an operation that can notably increase the uniformity and cleanliness of the finished product. In order still further to increase the capacity of these "dressers," a "gyro-whip" high-speed sifter was invented by Thomas Cecka and placed on the market in 1937 by the Richmond Mfg. Co. Though high-speed sifters make more revolutions per minute than those of low speed, they have a throw or circle of rotation only half as great, so that the stock

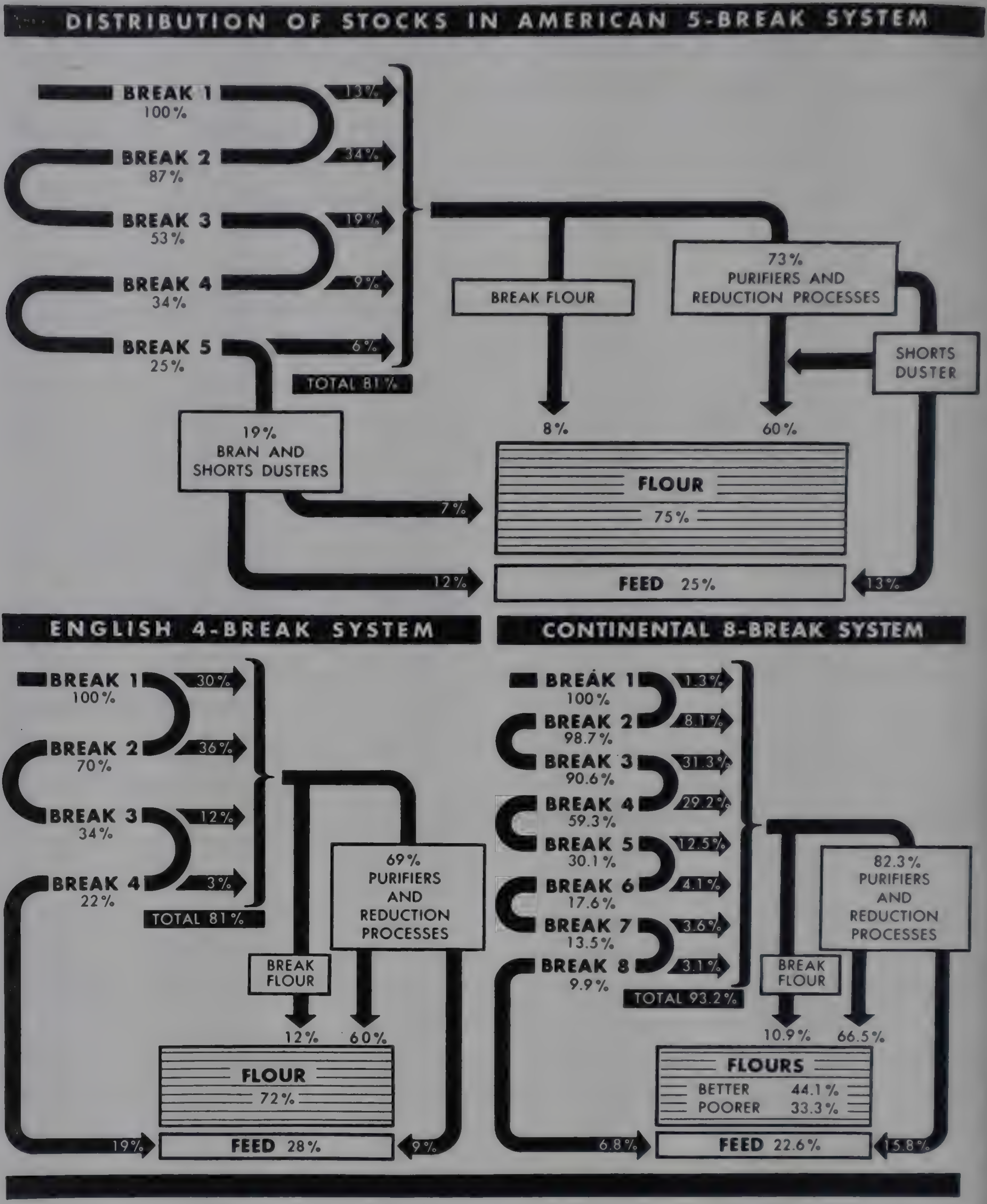

DISTRIBUTION OF STOCKS IN AMERICAN 5-BREAK SYSTEM
BREAK 1 100%
BREAK 2 87%
BREAK 3 53%
BREAK 4 34%
BREAK 5 25%
13%
34%
19%
9%
6%
TOTAL 81%
19% BRAN AND SHORTS DUSTERS
7%
12%
BREAK FLOUR
73% PURIFIERS AND REDUCTION PROCESSES
SHORTS DUSTER
8%
60%
FLOUR 75%
FEED 25%
13%
ENGLISH 4-BREAK SYSTEM
BREAK 1 100%
BREAK 2 70%
BREAK 3 34%
BREAK 4 22%
30%
36%
12%
3%
TOTAL 81%
69% PURIFIERS AND REDUCTION PROCESSES
BREAK FLOUR
12%
60%
FLOUR 72%
FEED 28%
19%
9%
CONTINENTAL 8-BREAK SYSTEM
BREAK 1 100%
BREAK 2 98.7%
BREAK 3 90.6%
BREAK 4 59.3%
BREAK 5 30.1%
BREAK 6 17.6%
BREAK 7 13.5%
BREAK 8 9.9%
1.3%
8.1%
31.3%
29.2%
12.5%
4.1%
3.6%
3.1%
TOTAL 93.2%
82.3% PURIFIERS AND REDUCTION PROCESSES
BREAK FLOUR
10.9%
66.5%
FLOURS
BETTER 44.1%
POORER 33.3%
FEED 22.6%
6.8%
15.8%

Figure 124. Characteristic stock divides in mills with different numbers of breaks. Differences in distribution are discussed in the text. The percentages given, though typical, would not be exactly duplicated by any mill.

actually has less velocity and therefore has more opportunity to find the holes in the sieves and suffers less attrition, increasing capacity and improving quality at the same time. After their utility had been proved for flour dressing, high-speed sifters were put to work in other parts of the mill.

In the average mill it takes the stock about fifteen minutes to move from the first break to the packing room. Packers consist of devices for feeding the flour into a container, for causing it to settle by "possing" (shaking down) or otherwise, for weighing the contents in the course of its flow, and for cutting off the flow when the required weight is reached. Simple ones were in use even in Evans' day. Even small irregularities in weighing can cause great losses if they average overweight, and great customer dissatisfaction when packages are light. A 3-ounce overweight on 100-pound sacks (an overweight of under one fifth of 1 per cent) in a mill of 6,000-cwt. capacity will cause a loss of $6,000 in a year's time.

We must now look in more detail at the system of operations from the first break to the flour bins. We shall base our analysis primarily on the admirable flow sheet for a 500-barrel (1,000-cwt.) mill prepared for *A Correspondence Course in Practical Milling* by the Dunwoody Industrial Institute, Minneapolis, a nonprofit organization, in collaboration with the *Northwestern Miller*. It was the distribution of stocks in this mill that gave us the diagram for the five-break system in Figure 124. We shall supple-

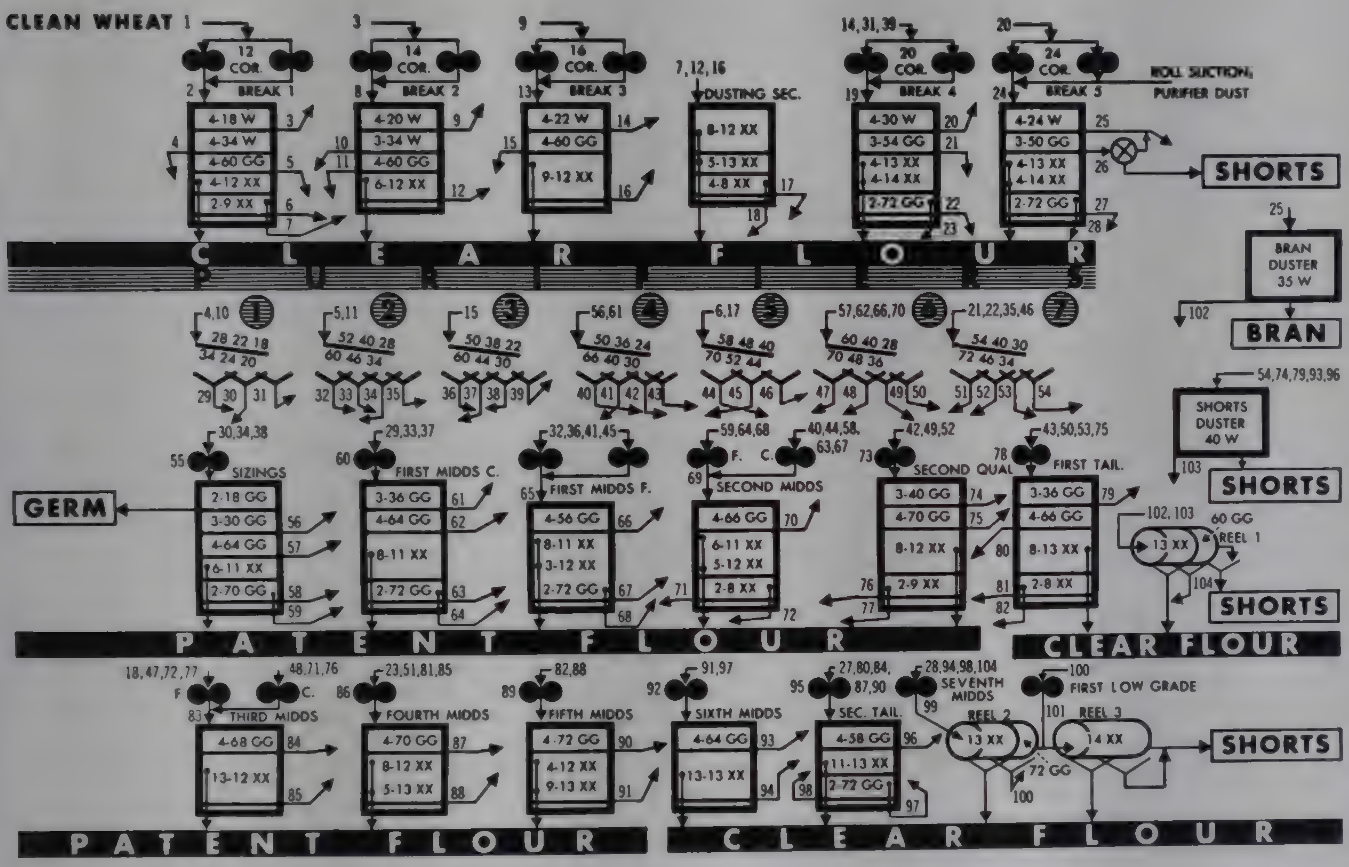

CLEAN WHEAT
BREAK 1
BREAK 2
BREAK 3
DUSTING SEC.
BREAK 4
BREAK 5
ROLL SUCTION, PURIFIER DUST
SHORTS
BRAN DUSTER 35 W
BRAN
CLEAR FLOUR
PURIFIERS
SHORTS DUSTER 40 W
GERM
SIZINGS
FIRST MIDDS C.
FIRST MIDDS F.
SECOND MIDDS
SECOND QUAL.
FIRST TAIL.
REEL 1
PATENT FLOUR
THIRD MIDDS
FOURTH MIDDS
FIFTH MIDDS
SIXTH MIDDS
SEC. TAIL.
SEVENTH MIDDS
REEL 2
FIRST LOW GRADE
REEL 3

Figure 125. Flow sheet for 500-barrel (1,000-cwt.) mill. Light-faced numbers associated with arrows indicate stocks; the direction of the pointers shows where the machine receiving the stock is symbolized in the diagram. Thus scalp stock 3 of the first break goes to the second break; graded stocks 4 and 5 to purifiers 1 and 2; etc. Heavy-faced numbers indicate (before the dash) the number of sieves of a given mesh in a sifter, and (after the dash, or in purifiers) the size of the mesh: W signifies *wire*, and GG *grit gauze*, the numbers indicating openings to the inch, while XX signifies *flour meshes*. Stock 26 can be valved either directly to SHORTS, or to a bran duster for treatment to recover more flour.

ment our description by suggesting some of the differences in flow that might be found in larger plants.

Figure 125 gives a complete flow sheet for this mill. After the chop from each of the first four breaks has been scalped to provide material for the next break, it is graded and dusted. The coarser stock is sent to purifiers to be freed from bran and classified by size for treatment by the reduction rolls; the almost flourlike "dunst" of the first three breaks goes to a dusting section; the flour made at each break is sent to packing bins; the residue of materials from the fifth break is routed to dusters and other machines at the tail of the mill for a final clean-up. A larger mill would require many more machines, including more break pairs, perhaps with different corrugations, and would set the rolls a little farther apart; it would use coarser sieves on the sifters, and would send the stocks from each break to their own purifiers, which would be clothed appropriately; the later reductions and siftings would be more numerous and more highly specialized.

Even in this 500-barrel mill there are 62 machines in the break and reduction sections, without taking account of facilities for dust collection:

Two pairs of rolls for each of the five breaks	10
A duster to sift out additional flour from the finer stocks of the first three breaks	1
Two sifters to handle the chop from each break	10
Purifiers to handle stocks from the sifters of the first four breaks	7
Pairs of reduction rolls, handling stocks from purifiers for the most part	16
Sifters to handle reduction-roll stocks	13
Centrifugal reels to handle stocks at tail of mill	3
Shorts and bran dusters to finish off tail-of-the-mill stocks	2

The sifters of this mill have 408 sieves, in addition to the other cloths on the reels at the tail of the system.

Figure 126 schematizes the flow of stocks for the first two breaks and first two reductions. The coarse separates of the first purifier are combined with somewhat similar stocks from nearer the tail of the second and third purifiers and sent to the first of the reduction rolls (the sizing rolls), which are set to flatten (but not break) the germs so that the sizings sifter can scalp them off. The fine separates of the first purifier are combined with other stocks from the second and third purifiers for reduction by the first coarse middlings rolls. The scalp of these rolls is combined with the first graded stock of the sizing rolls for treatment by the fourth purifier; and other stocks are handled together as indicated. In a larger mill some of these stocks would receive separate treatment, which would require different sieve and roller arrangements farther on.

In our mill twenty-one major machines were required to initiate full-scale production of flour, which begins only after the first coarse middlings reduction, where 25 per cent of the total extraction is made, all of patent grade. In preparing to make this flour, an additional 7.3 per cent of the flour was made at the first three breaks (4.8 per cent) and the sizings rolls (2.5 per cent), the latter also of patent quality. Nearly half of the flour, and that of the highest grade, is obtained from the chop of the six pairs of sizings rolls and first and second middlings rolls, coarse and fine. This flour has passed through cloths with from 13,456 to 15,625 meshes to the square inch. It is interesting, however, that some of the poorer flours will pass through much finer cloths (Figure 127): it is not the fineness of the flour alone that determines its quality, but also its freedom from contaminations and to some extent its granularity. Overgrinding can change its colloidal characteristics and impair the dough-making properties of its proteins.

Graded stocks from only the first six sets of reduction rolls are repurified; thereafter the larger particles from one set of rolls are scalped off and sent either to rolls farther along in the process or to a duster, not unlike that in Figure 82, to effect additional separations. After every grinding, of course, there is a sifting. As one moves toward the tail of the mill, the

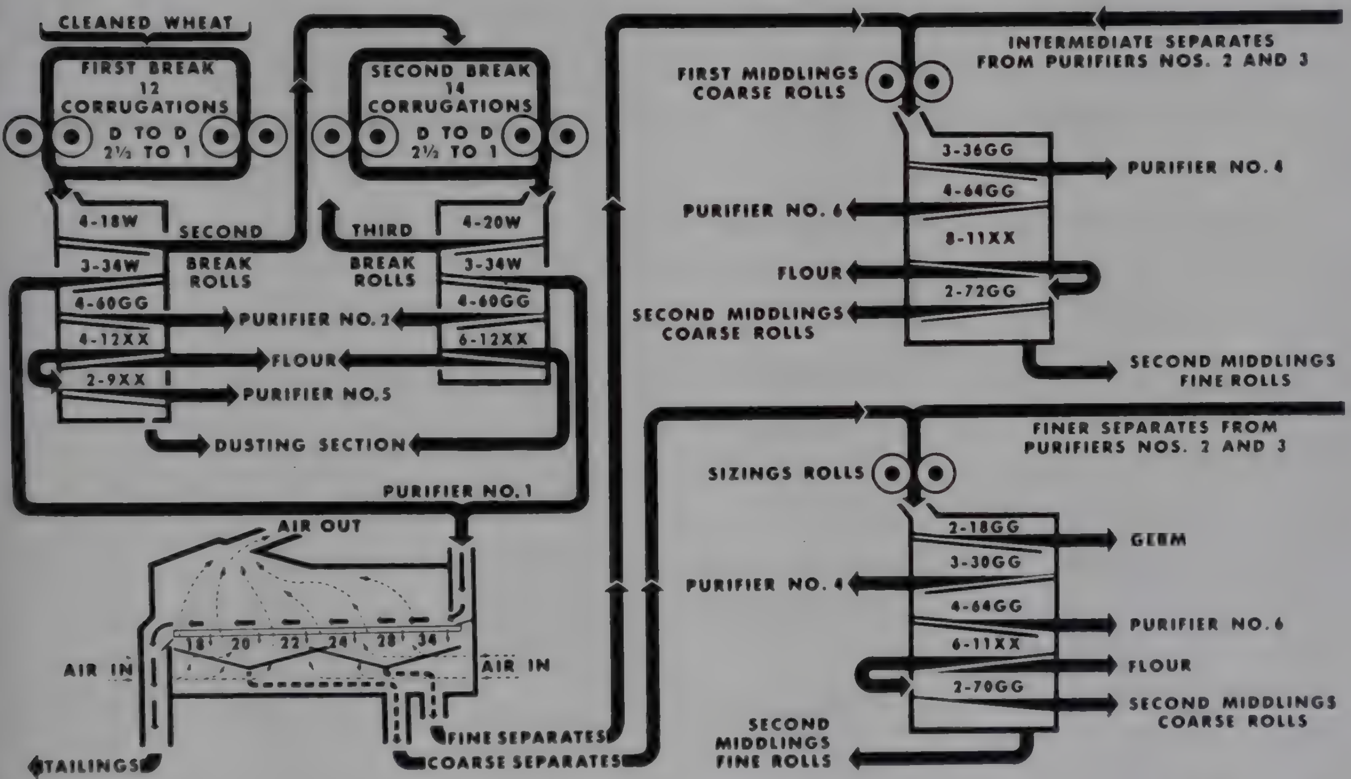

CLEANED WHEAT
FIRST BREAK
12
CORRUGATIONS
D TO D
2½ TO 1
SECOND BREAK
14
CORRUGATIONS
D TO D
2½ TO 1
4-18W
SECOND
3-34W
BREAK
ROLLS
4-60GG
4-12XX
2-9XX
THIRD
BREAK
ROLLS
4-20W
3-34W
4-60GG
6-12XX
PURIFIER NO. 2
FLOUR
PURIFIER NO. 5
DUSTING SECTION
PURIFIER NO. 1
AIR OUT
18
20
22
24
28
34
AIR IN
AIR IN
TAILINGS
FINE SEPARATES
COARSE SEPARATES
INTERMEDIATE SEPARATES
FROM PURIFIERS NOS. 2 AND 3
FIRST MIDDLINGS
COARSE ROLLS
3-36GG
PURIFIER NO. 4
4-64GG
PURIFIER NO. 6
8-11XX
FLOUR
2-72GG
SECOND MIDDLINGS
COARSE ROLLS
SECOND MIDDLINGS
FINE ROLLS
FINER SEPARATES FROM
PURIFIERS NOS. 2 AND 3
SIZINGS ROLLS
2-18GG
GERM
3-30GG
PURIFIER NO. 4
4-64GG
PURIFIER NO. 6
6-11XX
FLOUR
2-70GG
SECOND MIDDLINGS
COARSE ROLLS
SECOND
MIDDLINGS
FINE ROLLS

Figure 126. More detailed view of the flow through the first two breaks, the first purifier, and the first two reductions, of the 500-barrel mill whose complete flow sheet is given in Figure 125. Each sifter has 17 sieves, as indicated by the numbers preceding the dashes in the boxes by which they are represented. The other numbers and letters in these boxes and in the purifier diagram indicate the sieve meshes: W is for *wire*, and GG for *grit gauze*, and the numbers show strands to the inch, while the XX numbers are flour cloths.

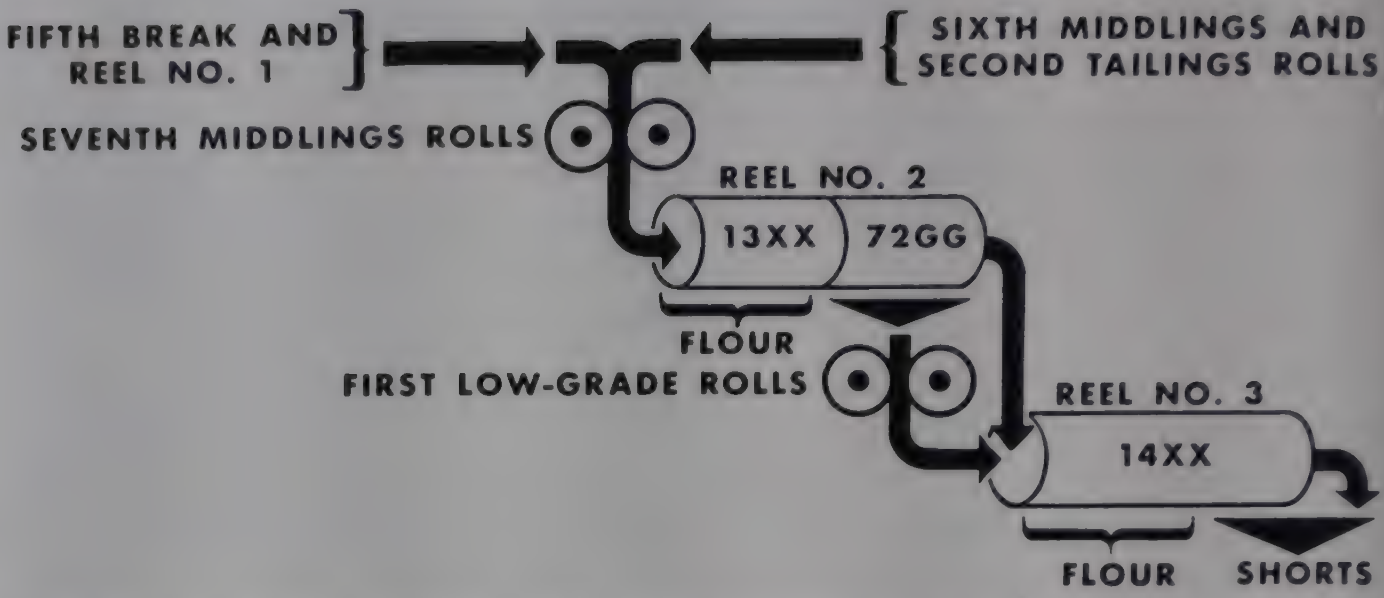


Figure 127. Treatment of the stock by centrifugal reels at the tail of the mill. The XX cloths are for flour, 13XX having about 17,000 meshes to the square inch, while 14XX has nearly 20,000.

stocks become increasingly fuzzier and dustier; more of the extremely delicate cellulose coatings of the starch cells of the endosperm are broken and released, exposing the minute starch granules within to fermentation in a way that would contaminate the flour. No short patent flour is obtained from the last five sets of reduction rolls in our mill, although their grind does go to make up a long patent. The first six reduction rolls furnish about two thirds of the best flour made by the mill, while the middle five yield the rest.

All recovered bran, except that derived from exhausts, comes from stocks that have passed through a number of breaks; a bran duster is used to loosen flour from the bran. Material rejected by the bran duster is re-treated by rolls and centrifugal reels to obtain still more flour and shorts, another feed material containing less crude fiber than bran; a number of grades of feed commodities are recognized, to some of which the term "middlings" is sometimes confusingly applied. The tailings of later purifiers and the less pure materials of later reduction rolls are sent to a shorts duster, similar to the bran duster, but with wire of larger mesh, and, as shown in Figure 127, at the very tail of the mill the last vestiges of flour are teased from the many-times-treated stock by rollers and centrifugal reels.

The mill we have been describing has 22 flour streams, ranging in size from the 25 per cent of patent flour derived from the first middlings rolls to the 0.6 per cent of low grade made by the fifth break. Each stream has characteristic ash and protein percentages, and differs from other streams in vitamin content and baking quality. In general, the amounts of ash and protein increase as one moves toward the tail of the mill; the unseparated bran which raises the ash figure is also rich in protein. About half of the flour made averages 0.36 per cent ash, indicating 0.75 per cent bran in the endosperm; only one quarter of the flour averages more than 0.374 ash and therefore contains more than 1 per cent bran. By combining streams an almost endless variety of flours could be blended in a modern mill if there were a demand for them; but the American public is strongly interested in getting the whitest possible flour, no doubt because dark flours look dirty and whiteness is associated with purity. Public taste through the centuries has overwhelmingly preferred white bread to dark as a dietary staple, whenever it could be made and there was money to buy it.

New methods in addition to dressing by high-speed sifters just before packaging have been found to satisfy this preference for whiteness, and at the same time to improve the flour. Freshly ground flour has a yellowish tinge – it contains small amounts of carotin, the coloring agent also found in carrots. This color is naturally oxidized with the passing of months, high-grade flours of bread wheat ultimately becoming creamy white. This bleaching can be greatly hastened by adding oxidizing gases or powders, or by submitting the flour to nitrogen peroxide produced electrically; J. N. Alsop offered this, the first bleaching process for flour, in 1904. Since 1920 the Federal Government has permitted flour to be bleached by approved means, provided the label on the package clearly states the fact. Bleaching does not alter the color of any dirt, bran, or germ that may be mixed with the flour, and, in fact, makes contaminations more noticeable. Some bleaching agents, as well as other substances, including malted flours, called "improvers," increase the fermentation period of doughs, or add to their toughness and stability, enabling bakers to make better bread from otherwise unsatisfactory wheats. In addition to bleaching and improving flours, modern millers also make a variety of special flours, including not only numerous whole-wheat, "graham," self-rising, pancake, and cake flours, but also flours prepared according to the specifications of baker customers.

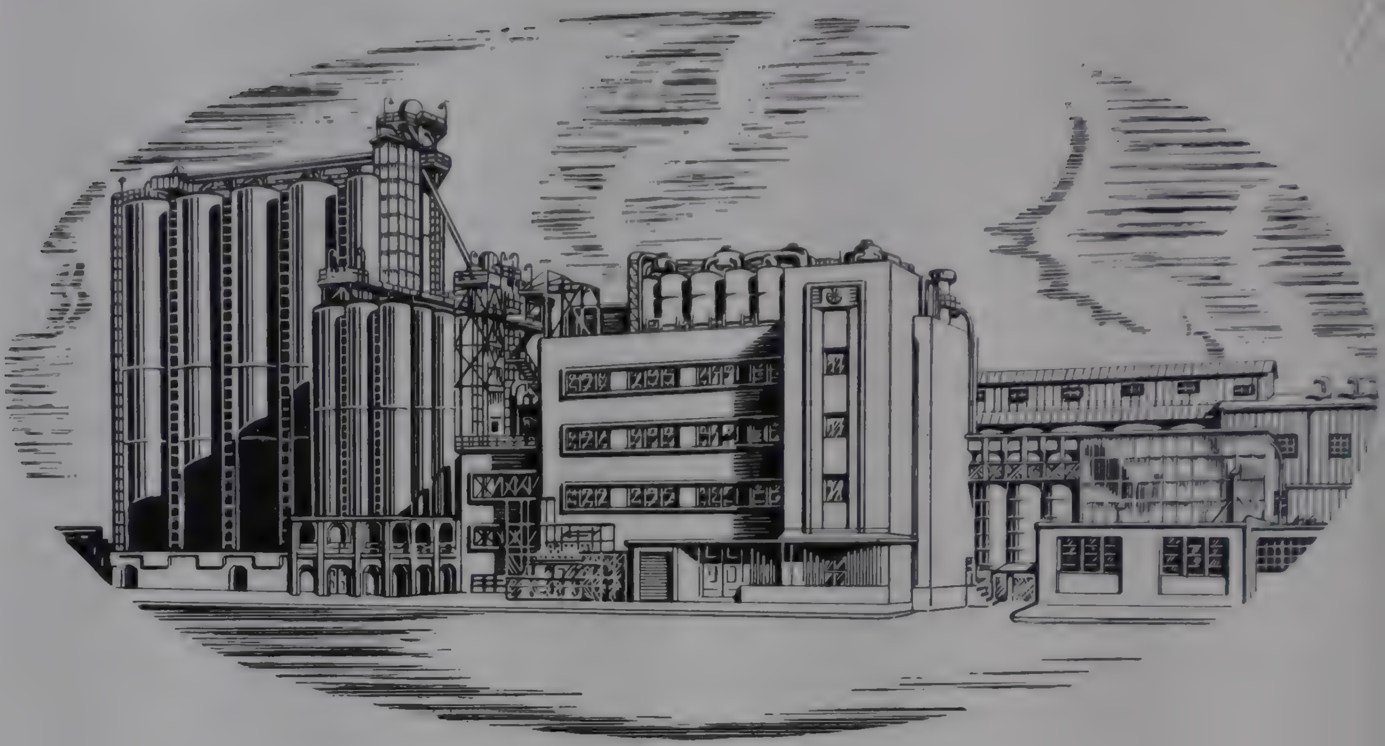
There was a second aspect of the preference for whiteness that could not be resolved until recently. From at least the time of Sylvester Graham, who died in 1851, millers have been severely criticized by a few for excluding bran and germ in their effort to make as white flours as possible. With a better understanding of the comparative digestibility of the various parts of the wheat berry, however, the arguments of those who advocated whole-wheat or "graham" breads on the score of their including more of the muscle-building proteins fell to the ground. It is true that typical white flours contain about 12 per cent protein, as compared with the 15 per cent in bran and 26 per cent in germ; but experiments conducted by the Department of Agriculture have shown that the protein in white flour is 88 per cent digestible, while that in bran is only from 28 to 45 per cent assimilable, depending on whether the bran is coarse or fine. In addition bran lessens the digestibility of other proteins, and interferes with the absorption of calcium and iron – metals needed in the human diet. It is also questionable whether bulk in the diet can best be secured through consuming large amounts of bran; its sharp edges sometimes irritate sensitive intestinal linings. When fed to animals, however, bran is more thoroughly digested; in this indirect way it can contribute to man's diet. Also the protein of white bread made with milk is superior to that of bread made from whole wheat mixed with water.

If the germ were included, its oily constituent would soon become rancid and affect the keepability of the flour. Millers therefore scalp off the germs in the bolting which follows the first reduction grinding; they are flattened by the sizings rolls at this point (Figure 126), while the more friable large middlings pass through. In recent years a good special market for wheat germ has grown up, adding to the miller's income and supplying those who can use it with this valuable constituent of the wheat berry.

As the muscle-building and bulk arguments for dark flours faded, and as the principal concern of nutritionists turned from the energy-giving characteristics of foods to their "protective" aspects – from quantity of intake and calories to vitamins and mineral constituents of the diet – white flour came under far more serious criticism. Certain substances are needed in minute amounts by men and animals, and no doubt by plants, for satisfactory growth and nutrition; when these substances are absent or deficient, the life processes are seriously impaired. The wheat berry is rich in some of these substances, especially those belonging to the so-called vitamin B complex; but for the most part these elements are so located in the berry that they are largely eliminated from white flour. Before enrichment, a patent flour containing 63 per cent of the wheat berry will include only 8 per cent of its thiamin, 10 per cent of its niacin, and 21 per cent of its riboflavin, all members of the B group of vitamins. Thiamin is essential for growth, for the utilization of sugars and starches to yield body heat and energy, for the maintenance of normal appetite, for normal recovery from fatigue, and for normal tone and proper functioning of the digestive tract. Niacin is essential for normal growth and development; a deficiency of niacin produces pellagra, a condition involving skin lesions, gastric disturbances, and nervous disorders. Riboflavin is essential for normal growth and development; a deficiency leads to physical abnormalities due to lack of oxygen within body cells.

As the need for these protective elements in the diet became more apparent in the late 30's, the position of the miller was not enviable. He was eliminating health essentials from his flour, but could do little about it. Of course, when bread was eaten as part of a rounded diet including ample milk, green vegetables, and fruits, no harm was done; but this diet was hardly calculated to maintain, much less extend, the miller's business. In an effort to solve the problem, General Mills selected a number of thiamin-laden streams to make an excellent vitamin flour: it failed to win favor because it was somewhat darker than the usual patents.

A solution appeared when chemists learned how to produce enough vitamins to permit their addition to white flour. British millers made a beginning in 1939 by adding thiamin; in 1940 practically the entire American milling and baking industry embarked on an enrichment program. Shortly thereafter specifications for the quantities of thiamin, niacin, riboflavin, and iron which must be contained in flour labeled "enriched" were established by the government. Iron was included because it is found in the wheat berry; it is essential to form the hemoglobin in red blood cells required to carry oxygen from the lungs to the body cells, and is an essential constituent of all soft tissues. If all white flour consumed in any form were enriched, cereal products would contribute about 40 per cent of the thiamin, 45 per cent of the niacin, 24 per cent of the riboflavin, and 45 per cent of the iron recommended for the diet of the average American. Thanks to enrichment, the question of white bread versus brown is no longer of dietary importance. Thus when undernourished German children were given three quarters of all their calories in the form of bread – as compared with well under one third for the average American – no health differences were found between groups that consumed an 85-per-cent-extraction brown bread enriched with calcium and vitamins to the level of the wheat berry, and groups that ate a 70-per-cent-extraction white bread enriched to the 85 per cent level. Enrichment has been one of the great forward steps in modern milling, an expansion of its service to the public made possible by the scientific advances in its own and related fields so characteristic of these times.



CHAPTER XIX

The New Era of Organization and Research

> You can influence research environmentally, but you cannot lead it. You must follow where research leads.
>
> —James F. Bell

BY THE latter decades of the nineteenth century, the American people had spread across a broad continent, settling the huge territories to the west not as colonists but as citizens establishing new democratic states. The United States was saved from the petty regionalism characteristic of other great continental areas by its common language and the common institutions which the settlers everywhere carried with them, but most of all by the federal union binding all regional governments together in one political and commercial unit. The telegraph had come in time to provide a continental system of communication, and a railroad network tied together all the country's widely dispersed sources of supply and its many distant, concen-

Chapter head oval. Los Angeles plant of General Mills, Inc. From left to right the the four major sections of the plant are shown: for reception and storage, for cleaning and tempering, for the production of finished products, and (in the background) for their packaging and shipment.

trated markets. The United States had swiftly developed an economic interdependence between its sections, paralleling their political union.

The great new grain-raising territories of the Northwest were in urgent need of the manufactured goods of the East – farm equipment, household furnishings, textiles, metal wares of all kinds; the East was in need of the foodstuffs which the West was producing at a hundred times its own capacity to consume. The physical problems of transshipping and distributing these immense quantities of goods were staggering. There was an era of feverish building of rival railway lines connecting the new and old territories, and then an era of cut-throat competition for the lucrative business they could win from each other. It was becoming clear that in this nationwide trafficking any isolated, small-scale producers were at a hopeless disadvantage: even their own local markets often could be supplied more economically by larger producers, even at a distance, manufacturing under more favorable circumstances and in great volume at lowered unit costs.

These developments were having their effect in the decline of community milling, already noted, and in a growing tendency for large mills to draw together in groups under the management of men who had proved their ability as able, vigorous, farsighted executives. Already by early 1889 a large part of the milling capacity of Minneapolis was in the hands of a few individually owned companies. The Washburn Crosby Co., incorporated in that year to lease Governor Washburn's mills from his estate, had a capacity of 8,500 barrels. C. A. Pillsbury & Co. operated three mills, with a somewhat greater capacity, their A mill at that time being the world's largest flour mill. The Minneapolis Flour Manufacturing Co., formed in 1889, also had three mills, with a capacity of 3,500 barrels; the Washburn Mill Co., owned by W. D. Washburn, a brother of the governor, had a single mill in Minneapolis and another in nearby Anoka with a combined capacity of 2,800 barrels.

But these groups of mills were still very largely personal enterprises, under the control of individuals or small groups of partners – their operating organizations little more than expanded versions of the smaller activities out of which they had grown. They had reached a point of size where they had to obtain supplies from distant fields and seek markets all over the country and overseas, but they continued to be run on the principles of individual ownership. The time was at hand when this type of administration and the contiguous plants which were all it could manage would prove inadequate to meet the social and economic needs of the new age. To cope with these needs, a strategically dispersed system of purchasing, storing, transporting, processing, and marketing would have to be evolved, with wholly new operating techniques to match. To manage such a system successfully would call for new arts of organization, policy making, merchandising, economic analysis, human relationships, and planning for the future.

This radical evolutionary change was required not only in milling but in all the basic American industries – steel, chemicals, transportation, communications, and a host of others. To serve a continental nation called for many continental networks each supplying a specific want, each like a dispersed army operating through chains of command that terminate at the top in a general staff rather than a single commander. By enforcing operational changes, the twentieth century would make its most distinctive contribution to the progress of milling as of other industries, leading in turn to great technological and scientific advances. These latter could not have occurred without the organizational changes that preceded them. And, naturally, so drastic an evolutionary process would need decades for its completion.

In the early stages of the process, the milling industry along with many other American industries would suffer brief but severe growing pains. The 90's were the period of "trust" formation, a movement toward the concentration of industries under unified financial rather than operational control, with the monopolistic objectives of dominating markets, controlling prices, and making quick profits in stock manipulation rather than continuing profits through the adaptation of large-scale production to public service. In the milling industry this trend was accelerated by British financiers, who had invested heavily in American railroads and brewery combinations and now turned their attention to flour milling. In 1889 they acquired control of the Pillsbury mills and the water-power companies at Minneapolis, as well as some northwestern grain elevators. C. A. Pillsbury was retained to manage their milling activities, and stock was offered for sale abroad for the Pillsbury-Washburn Co., which gained the prestige of the Washburn name when W. D. Washburn also joined the combination. In 1890 the new corporation was prevented only at the last moment from securing a lease on the mills operated by the Washburn Crosby Co., which would have concentrated a large part of the milling at Minneapolis under a single control. In 1891 the Northwestern Consolidated Milling Co. was formed under the leadership of A. C. Loring to combine six Minneapolis mills with a total capacity of 11,400 barrels.

In a whirlwind campaign which began in 1898, a New York promoter, Thomas A. McIntyre, attempted to organize a flour trust under the title of the United States Flour Milling Company. He acquired mills and elevators in New York City, Buffalo, Syracuse, Duluth, Milwaukee, and Superior, but for domination and prestige it was essential that he obtain large capacity at Minneapolis. The American managers of Pillsbury-Washburn prevented his obtaining that company, and in a breathless contest to gain the lease on Governor Washburn's mills he forced the

Washburn Crosby Co. to purchase them from the governor's estate in 1899. He did obtain the Northwestern Consolidated, and also another Minneapolis mill; but his company was heavily overcapitalized and went into receivership in 1900, eventually becoming the present Standard Milling Co., which rates eighth in production among American flour manufacturers.

The history of McIntyre's adventure was typical of the trust movement as it fared in milling. It was not only resisted by important millers who still looked on themselves as producers rather than promoters, but the combinations it formed tended to collapse under their own weight. The economies and efficiency that may result from the unified operation of many units do not occur automatically; they result only from applying the special planning procedures and administrative techniques we have mentioned, arts of which the trust promoters knew no more than anyone else in their day and apparently cared less. Their object too often was solely the marketing of stock rather than the marketing of improved products, and if more shares were issued than could reasonably be assured a safe return — if the stock was watered — disaster was almost certain to result. Profits too declined under absentee management concentrating on financial manipulation rather than efficient production and merchandising, and thus the trust promoters defeated their own ends. Very soon their monopolistic tendencies would be effectively curbed by the passage of the Sherman Anti-Trust Law, one of the most important statutes in our history, which firmly established the competitive system in American business, with all the incentives to progress it provides.

Promotional characteristics had undermined the Northwestern Consolidated, before its entry into the trust, so that it had been forced to undergo a reorganization in 1895. Although the units forming the Pillsbury-Washburn Co. had shown profits averaging $800,000 over the six years prior to 1889, after the combination they averaged only $412,000 for the nine years through 1898, so that dividends were frequently passed. In 1908 the company failed and was reorganized under conditions which led to its sale by the British owners to the American operating company in 1923.

The milling industry was not inducted into its modern era of usefulness and prosperity by the kind of manipulators who had their field day in the 90's. Its future would be shaped by men who still looked on themselves as millers and felt a strong sense of responsibility to their craft. And so the same decade that witnessed the ambitious schemes of the trust-makers also marked the emergence of the modern merchant miller, with his acute awareness of the new economic and social circumstances in terms of which milling must operate — the conditions created by the maturing of a great continental nation.

There were several major considerations, little understood at the time by others, illuminated by no prior experience, which shaped the policies of these pioneers of a new era. In the first place, milling more than any other industry had to decentralize its operations to an unprecedented extent if it was to serve a nationwide market efficiently and economically. It was absurd that the grain from thousands of farms scattered all over the grain-raising areas of the Middle West and the West should be carried to a central point, even a point as favorably located as Minneapolis, and the finished products carried again from that focal point to users spread all the way from Maine to California: storage elevators and mills must be located in the major flow streams of the wheat as it moved naturally from the fields to the consumer. And such a strategic network of operations must be plotted not only with reference to sources of supply and ultimate markets, but with reference to the major railway arteries and the costs of railway transport. Shipping costs might represent the difference between profit and loss, even success and failure, in an industry which depended on the transport over long distances of huge quantities of raw materials and finished products.

Another policy-making consideration was the fact that for successful nationwide marketing a more direct relationship between miller and consumer must be created. In the days of community milling the miller had dealt directly with his neighbors, but with the expansion of output in the mid-nineteenth century, having few contacts outside his own community, he had entrusted the marketing of his products to jobbers. These jobbers had gradually become powerful middlemen, often dictating policy to the miller, promoting their own brands, and giving the consumer what it suited them to give: they were a barrier between the producer and his customers. In modern, large-scale, competitive manufacturing, the producer must establish his own identity in the consumer's mind, assume responsibility for his products, and create public confidence in their value. In 1890 the Washburn Crosby Co. was first among millers to speak directly to nationwide users of its flour by means of a modest advertising appropriation of $40,667. Changes in packaging, to adapt the unit of sale to the buyer's needs, were also a necessary step.

These were the small beginnings of a marketing policy now followed by all large millers, to make their products known to the public under their own brand names, and to place the full responsibility for these products with the manufacturer and not with the jobber or retailer. Today's achievements in milling would not have been possible without this development of marketing. Jobbers still perform a useful function, as in distributing less than carload lots to small purchasers, but they no longer dominate the market or influence public acceptance.

Basic to all other considerations was the problem of internal organization, as the milling companies outgrew individual direction. In a combination of many units under one management the separate units may continue to operate much as before, except for the improvements made possible by larger resources for research and by pooling of experience; but the justification of bigness in industry lies in the production of more and better goods, of standard quality, at lower cost, more evenly distributed to the population. In an industry operating over a widely scattered territory these objectives of economy, quality, and distribution can only be attained by a wholly new mechanism of management. Responsibilities must be widely distributed, with an equal measure of independent authority, so that the infinite details of a huge business can be dealt with promptly and effectively, on the spot, by specially trained men; but all these executives must be guided by clear over-all policies which direct their actions toward common objectives. And throughout such a far-flung network, the organization must encourage the rise of a steady stream of fresh young executive talents if it is to grow with an expanding environment.

The acknowledged leader in these operational, marketing, and management developments was James S. Bell, who came to the presidency of the Washburn Crosby Co. in 1889. Under his guidance this company was the first to graduate from personal management to modern corporate status, although none of the requisite transformations would reach their full maturity for several decades, and many other individuals would contribute to them.

Already at the turn of the century the companies which had been increasing their capacities at Minneapolis were expanding into new territories, both west and east. James J. Hill had pushed his railroads westward in advance of settlement, largely because he was convinced that the hard-spring-wheat area would spread throughout the Northwest. Mills were built by Minneapolis interests in Montana, anticipating the same growth on which Hill had counted, and others at Louisville. In 1904, by starting a new mill at Buffalo, the Washburn Crosby Co. initiated that migration of Minneapolis millers eastward which was brought about in the first instance by the abolition of the free flour-storage privilege at Buffalo in 1901, and was given impetus by the decline of hard-spring-wheat milling at Minneapolis and by the hope of tapping Canadian wheat resources at Buffalo. The Pillsbury interests established themselves in Buffalo in 1922, Russell-Miller in 1923, and Standard in 1926. In 1908 Washburn Crosby made a modest start toward diversification of its activities by beginning the large-scale milling of rye.

The forces that had initiated these changes in the late nineteenth century continued to expand as the twentieth advanced. In the early years of the twentieth century, new lines of wheat flow gained volume, in addition to the old main line through Minneapolis and Buffalo to the East. The Gulf exit became important, as Kansas and states in the Southwest grew to major rank as producers of hard winter wheat. During World War I the exit by way of the Pacific entered the national picture, as California and the Far Northwest became important sources of supply. The problem of freight rates, with its shifting balance of advantage for this locality or that, became nationwide in extent, exerting a strong influence toward still further expanded operations under unified control. As the country grew, shifts of the population increased the consumers in certain regions much more rapidly than in others. During and after World War I a further decline in per-capita wheat consumption in this country created a grave problem for the miller, especially as Canada simultaneously began to make inroads in our world markets. New wheat areas in other countries became factors in world trade. In addition, there was a marked growth of nationalistic spirit everywhere, expressing itself in increasing restrictions on international trade.

It was in response to these factors—to new wheat fields, to changing freight differentials, to shifting populations, to alterations in the relationship between production and consumption, to a less favorable world outlook—that the millers of the Northwest, who had started as local suppliers but had won almost worldwide acceptance for their flour, found that they must make further adaptations if they were not to revert to their earlier status. A climactic step in meeting the new conditions was taken in 1928, when James F. Bell, son of James S., who had come to the presidency of the Washburn Crosby Co. a few years earlier, formed the great nationwide network of General Mills, Inc., around the nucleus of his own company. This was even more than a careful assembly of units strategically located with reference to new wheat fields, shifting population, changing rates, and altered consumption—it was the first attempt to give all these factors due weight in shaping a comprehensive plan for serving the whole people of a continental area. As such it opened up to the milling industry new areas of usefulness and profit. The present-day activities of General Mills, currently the largest factor in world milling, are mapped in Figure 128 as a graphic illustration of how far the modern milling industry has traveled in the direction of nationwide service, from its beginnings in thousands of small, isolated enterprises grinding out their imperfect product beside countless rushing millstreams.

Large-scale manufacture of this kind introduced many major problems, as we have indicated—organizational and economic especially. But it also introduced new and basic technological problems, and the solution of these has determined the modern development of the milling art. There is the problem of quality control, which demands unremitting attention in quantity manufacture, where it becomes essential that no variations in the quality of the product beyond predetermined limits shall be permitted, even though it may be processed in widely separated plants: a big baker would have just as little use for a batch of flour of slightly higher gluten

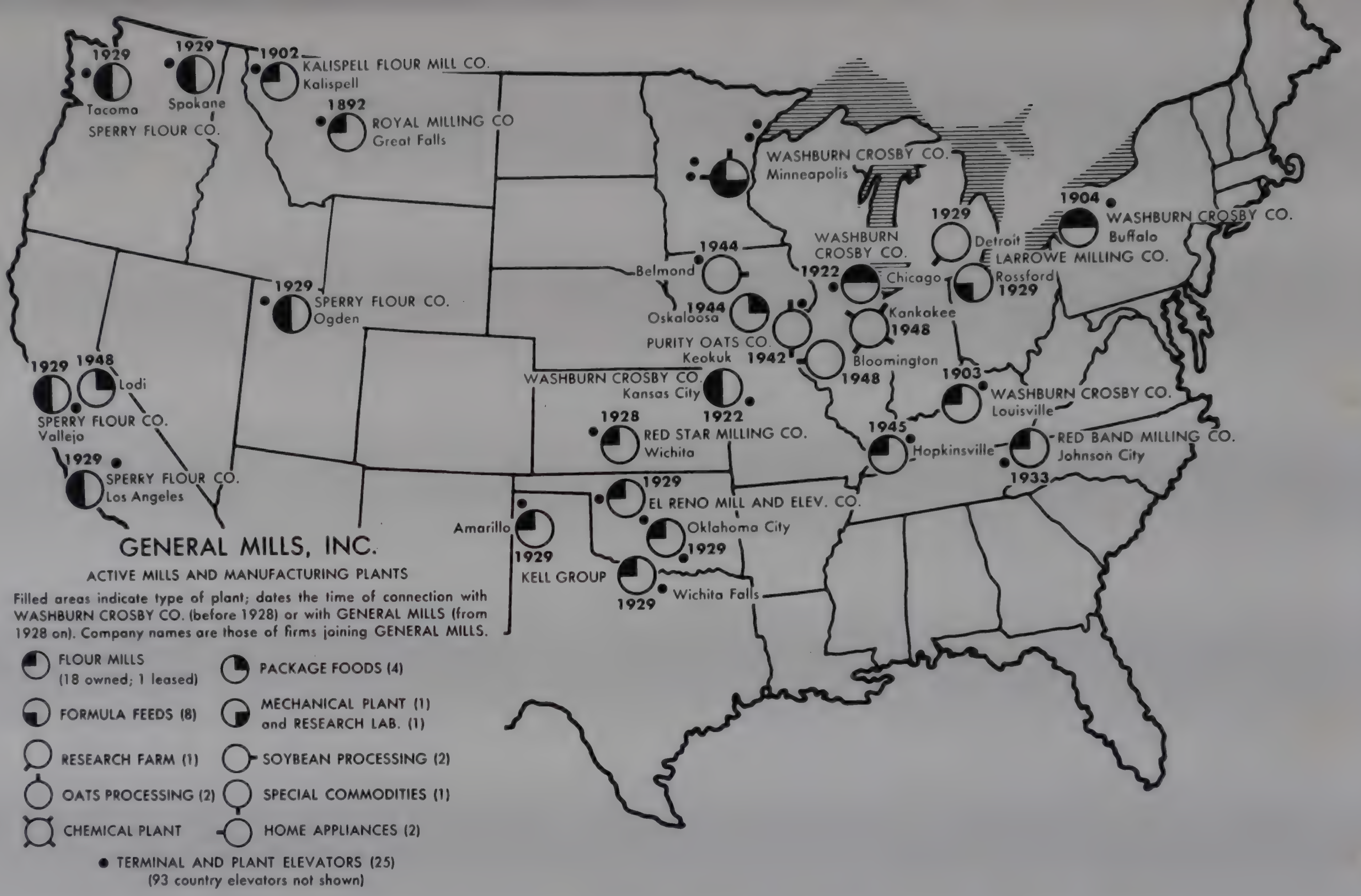

1929
Tacoma
1929
Spokane
SPERRY FLOUR CO.
1902
KALISPELL FLOUR MILL CO.
Kalispell
1892
ROYAL MILLING CO
Great Falls
WASHBURN CROSBY CO.
Minneapolis
1929
SPERRY FLOUR CO.
Ogden
1929
1948
Lodi
SPERRY FLOUR CO.
Vallejo
1929
SPERRY FLOUR CO.
Los Angeles
1944
Belmond
1944
Oskaloosa
PURITY OATS CO.
Keokuk
1942
WASHBURN CROSBY CO.
Kansas City
1922
1928
RED STAR MILLING CO.
Wichita
1929
EL RENO MILL AND ELEV. CO.
Oklahoma City
1929
Amarillo
1929
KELL GROUP
1929
Wichita Falls
WASHBURN
CROSBY CO.
1922
Chicago
Kankakee
1948
Bloomington
1948
1929
Detroit
LARROWE MILLING CO.
Rossford
1929
1904
WASHBURN CROSBY CO.
Buffalo
1903
WASHBURN CROSBY CO.
Louisville
1945
Hopkinsville
RED BAND MILLING CO.
Johnson City
1933
GENERAL MILLS, INC.
ACTIVE MILLS AND MANUFACTURING PLANTS
Filled areas indicate type of plant; dates the time of connection with WASHBURN CROSBY CO. (before 1928) or with GENERAL MILLS (from 1928 on). Company names are those of firms joining GENERAL MILLS.
FLOUR MILLS (18 owned; 1 leased)
PACKAGE FOODS (4)
FORMULA FEEDS (8)
MECHANICAL PLANT (1) and RESEARCH LAB. (1)
RESEARCH FARM (1)
SOYBEAN PROCESSING (2)
OATS PROCESSING (2)
SPECIAL COMMODITIES (1)
CHEMICAL PLANT
HOME APPLIANCES (2)
● TERMINAL AND PLANT ELEVATORS (25)
(93 country elevators not shown)

Figure 128. Active mills and manufacturing plants of General Mills, as of 1948; an example of the dispersal of production in strategic areas, located with regard to grain supplies and markets.

content as for one that was slightly deficient—both would disturb his formulas. There is also the problem of providing for, and of responding to, that research which has already greatly extended the frontiers of many industries and is now generally recognized as containing the most fruitful seeds of future stability and growth. There is the problem of the relations of a great corporate organization to the public at large—relations which involve advertising and marketing as we have already mentioned them, but in these times include many other forms of public information and public service. And there is the problem of maintaining a flow of new blood into management itself, keeping open the avenues of advancement for able young men whenever they may prove themselves among the personnel.

Efficient organization is, of course, a basic requisite for the successful solution of all other problems. As a company grows to great size, it is not easy to combine flexibility of operation, under localized administration, with centralized formulation of policy and continuous over-all planning. It has been accomplished in certain large milling organizations, as in other corporations of national scope, by a dual but interlocking system of operating divisions and administrative departments, in which the main business of the latter is to plan, coordinate, and test, while the main business of the divisions is to translate policies into action. Unity is maintained by executives who recognize this as their principal responsibility, and by boards and committees whose membership cuts across the departmental-divisional organization so that the voice of each group is heard in the counsels of the others. The major aim is to transform a complex, widespread assemblage of individuals into a quick-acting, sound-thinking team.

On the operating side, for example, a milling organization may include one or more grain-handling divisions, each with territorial jurisdiction over all matters connected with the purchase, storage, and sale of grain, including even its sale to the company's milling divisions for processing into salable products. Each grain-handling division is directly responsible to the grain department (its administrative counterpart), which is charged with the current development of prices, policies, and procedures; to the supervision of all grain operations; the coordination of the grain department with the flour and feed and the grocery products departments; and the review and recommendations on all plant projects in respect to grain facilities of such magnitude as to require executive approval.

The vice president in charge of the grain department sits on various boards and committees, so that the work of his department is coordinated with that of other departments and divisions, in the light of the general policies of the concern. One of these is an operating board drawn from all departments and divisions directly charged with production, on which representatives of finance, advertising, products control, research, etc., also sit. along with the executive vice president of the concern. Here the high-level policies of the board of directors, the president, or his executive council are implemented in sufficient detail to enable their complete execution by the groups concerned, without intellectual confusion or action at cross-purposes. The vice president of the grain department is also a member of a purchasing committee which determines general policy with respect to the purchase of the products and supplies, in the light of the company's inventory position and the state of various markets. He also belongs to a quality and standards committee on which representatives of the flour and feed and the manufacturing departments sit, along with the executive vice president of the concern and those responsible for products control and for research, so that all products will unfailingly measure up to predetermined standards.

The work of all other departments and divisions is organized similarly, each according to its particular needs, with the same coordination through boards and committees. Over all these particular agencies and coordinating groups stands an executive committee, on which the president of the concern sits as chairman. The function of the executive committee is to advise the president with respect to any problem of policy, administration, or procedure which he or any other member might raise. The president, of course, is responsible to the board of directors of the concern, who are elected by the stockholders and who function from day to day through their elected chairman. They it is who are ultimately responsible for management of the business of the concern.

Clearly an organization such as we have been describing calls for coordination and teamwork developed to a much greater pitch than would be found essential in a smaller enterprise. These attributes, however, are only the foundation for success in a big concern, for the individuals involved must not only cooperate – they must be able to act vigorously and to good effect if the enormous inertia of size is to be overcome. A big business has more need than a small one for high competence in its staff; but beyond even that it must *organize for vigilance* in its operations.

Gone is the day when the sensitivity of the miller's thumb was a sufficient guide to the quality of his product, or when his unaided senses of sight and hearing could tell him whether the operations of the mill were proceeding according to plan. The need for quality control along scientific rather than merely empirical lines was felt at least as early as 1886, when A. W. Howard founded a commercial testing laboratory at Minneapolis to which millers sent their flours for baking tests and for analyses of their contents. Stimulated by Jago's work on the chemistry of flour, the Washburn Crosby Co. set up a testing room in 1893 – the first such step to be taken by an American miller. Today every large miller determines precise quality standards for his products, of whatever kind, and bends every effort to see that they are maintained.

Each spring, representatives of departments of products-control will follow the wheat crop as its line of maturation moves northward from Texas to Canada at a rate of about one mile per hour. They determine the attributes and baking performance of wheats from every important section of the country, so that the grain department may formulate its purchasing program on the basis of complete current wheat information. In advance of processing, the manufacturing department is supplied with information on the milling quality of the available wheats, and is told how wheats should be blended to maintain the established standards. After manufacture the finished goods are studied as to attributes and performance, so that the company may be certain that they will continue to merit consumer acceptance. "A sale of flour to a baker or grocer is not really a sale at all; it is only half a sale. The sale is not completed until the consumer has entered the picture." And so the products-control department originates and supervises a number of technical aids for the baker – to help him solve his production problems, to improve his product, to help him merchandise his goods – while for the family trade it may work in close cooperation with a home-service department which tries out company products for home use and spreads information and builds good will among homemakers.

In the field of research, the constructive achievements possible only in large-scale operations are strikingly illustrated. Research had its beginning in American milling as a continuous effort carried on right down to the present when James F. Bell persuaded the Washburn Crosby Co. in 1898 to rent two rooms over a saloon in which to study the moisture and ash content of flour and the extraction of oil from the wheat germ; at that time he was still a student at the University of Minnesota. As late as 1930, when the Research Department of General Mills was formed, the entire scientific staff consisted of five chemists, who were studying bleaching agents and vitamin production. Today the staff numbers about four hundred, and is housed in a number of buildings, which include the most modern physical, engineering, chemical, and biological laboratories, a machine shop, and pilot plants, as well as a laboratory for the closely related activity of products control. Although the largest in the field, this is typical of the research activities carried on by other companies as well.

Some of the results of research merely lead to improvements in the traditional activity of the miller, or extend it into naturally associated areas. The grains have numerous possibilities unsuspected until modern scientific research revealed them. Thus the fundamental behavior of flours was improved by one concern through control of their natural enzymes, so that better bread could be made from the treated flours. This work led to a study of the vitamin content of wheat which resulted in the discovery, somewhat further afield, that vitamin D could be produced commercially by using low-velocity electrons to activate ergosterol.

Other research in areas associated with milling has opened up new markets for low-grade flours as a source of industrial starches and glutens. Whereas about 180 million pounds of starch are used every year in the American home, industry needs more than 1,000 million pounds, now mostly manufactured from corn. This starch is used in food products and as a sizing and finishing material for textile fabrics, a thickener for textile printing colors, a binder for packaged fuels, a paper-coating adhesive, and other things. The gluten in low-grade flours also has many industrial uses – for paper-coating adhesives and for stabilizing waxes and water emulsion paints to prevent their separation in layers. Among many other applications, it is a source of glutamic acid, which is an intermediate agent in synthesizing a number of pharmaceuticals, including folic acid, a member of the B-vitamin complex. From glutamic acid can be obtained monosodium glutamate, an intensifier of natural food flavors which is rapidly becoming a household condiment. In such ways as these flour from the tail of the mill can be turned into a source of profit for the miller and of desirable commodities for his customers, while simultaneously the milling industry is given greater stability through a widening of its markets.

Traveling only a little further out of his traditional orbit, the miller's interest in animal feeds and in wheat germ oils has led him to undertake soybean processing, for the protein of the soybean is a highly concentrated animal feed and is rich in an oil of many uses – as an ingredient of shortenings and oleomargarines, soaps, nonsoap detergents, ore flotation and emulsifying agents, paints and varnishes, linoleums and oil cloth, printing inks, heat-sealing adhesives, etc. Thus by taking an apparently simple, small step, the miller finds himself in an extraordinarily different environment – and one, too, of great possibilities for expansion. American production of soybean oil has increased from about 1 million pounds in 1922 to much more than 1,000 million pounds annually over the last few years.

Because soybeans are a source of fatty acids, the miller's research department is encouraged to study these substances generally. They are cheaply available in fish oils and in the mixed tailings of paper mills and vegetable oil refineries. Tall oil (from Swedish *tallöl*, pine oil), for example, is an extremely cheap fatty-resinous acid liquid which is of limited use in its primitive form because of its dark color, obnoxious odor, and physical properties; yet 32,000 tons of it are available every year from American paper mills alone, and by conversion it can supply many of the needs for fatty acids. Thus by easy stages a concern advances into the processing of materials that are so new that they have no past, but so adaptable that they are great reservoirs of potential usefulness.

The miller of medieval and colonial days drew his milling livelihood from a toll taken on the flour he ground; and to that the nineteenth-century American miller added a trade in feed. The low estate of such feed can be discerned from the fact that it was called *canal* in the northern United States and Canada – a corruption of the French *canaille*, "fit for a dog." Until the twentieth century, however, flour and feed between them practically exhausted the miller's sources of income. The extent to which diversification has freed the miller today from bondage to his most highly competitive product is indicated by the fact that while in 1932 flours and mill feeds amounted to 72 per cent of the sales of the largest producer in the field, in 1946 they accounted for only 55 per cent. A great number of products, unknown a generation ago, are included in the remaining 45 per cent.

The advantages of launching a new and desirable product are self-evident, but the public is seldom aware of the careful procedure that must be followed before such a product can safely be released for full-scale mass production. After a survey of potential markets has led to a decision that the product should be made and it has passed through laboratory preparation, research on a somewhat larger scale is usually necessary to develop practical methods of production. In the laboratory the primary aim is to perfect the product, without very much attention to cost or convenience; now ways must be found to manufacture it practically and cheaply. After these have been worked out, pilot-plant production is essayed with a small unit duplicating full production in all essential details. On the basis of this experience full-scale production is initiated under close engineering supervision, and finally the plant is turned over to regular work crews. At every stage difficulties crop up and have to be removed, until the final production scheme is as errorless as technical knowledge can make it.

Striking examples of the effect of research on modern mill design and processes may be seen in a new plant at Los Angeles, which, although it has a 3,600-sack capacity, is so advanced that it is regarded as a full-scale experimental mill – a combination of pilot plant and commercial enterprise (Oval, Chapter XIX). It is not, however, considered to represent the last word, but merely the present stage of progress. Every process and every machine has been subjected to searching study, and redesigned in an effort to advance it toward perfection as far as present knowledge will permit. A start has even been made in the reorganization of relationships between processes that may eventually lead to their relocation in the production sequence.

Here an all-out attack has been made on the basic problem confronting any manufacturer who deals with huge quantities of organic material, which almost invariably reaches him in an unclean or contaminated state – the problem of complete sanitation. Almost all wheat, as it arrives at any mill, carries the hazard of weevil infestation; and if any of the grain or grist lodges in crevices or static areas during its passage through the mill, these deposits become ideal breeding places for weevils and other insects.

The difficulty of preventing any such contamination is enormous: it must really be prevented—periodical cleanings or fumigations are mere palliatives.

The first step at the Los Angeles plant toward complete sanitation—and it also is a safeguard against the explosion hazard—was to design the mill in four separate, yet integrated, sections: for reception and storage, for cleaning and tempering, for grinding and sifting, for packing and shipping. A second step was to design the structure and redesign its equipment so as to eliminate all cracks, crevices, ledges, and static areas where grain, grist, or dust might lodge and remain. A third and a fourth important advance were to store the raw grain in an inert gas and to move the finished flour and nearly all the stocks by air instead of the elevators and conveyers with which a conventional mill is filled: air literally makes a clean sweep of its job, with a completeness that mechanical carriers cannot hope to rival. All processes are under much more precise instrumental controls than ever before.

The grain is delivered into the mill's storage section by semiautomatic box car unloaders which can be operated by one man. It is raised by bucket elevators into the storage tanks, which have a capacity of 300,000 bushels and are of welded steel instead of the usual concrete. They were constructed without either a tunnel underneath or a galley or headhouse overhead, eliminating spaces in which explosive dusts might accumulate. The grain is conveyed and distributed to the bins in weather-proof conveyers on the open roof, and the conveyers and tanks are blanketed inside with an inert, nonexplosive gas to eliminate the dust hazard and inhibit biological and even bacteriological life. Under these conditions infestations have almost no opportunity to spread, although not all foreign life in the grain is destroyed. Air-operated slide gates and electrical interlocks under remote control regulate the flow of grain.

In the cleaning and tempering department, in addition to a full line of separators and scourers, "Entoleters" are used to destroy insect life through impact of the grain against pins set in a rapidly revolving disk; this machine operates in the same general way as the old devices shown in Figure 92. The Earle flotation process is incorporated into the cleaning program (see page 330), and valuable materials are recovered from the water used in washing. The mill is equipped to do as versatile a job of tempering as the best English plants. As a novel feature made possible by the California weather, the tempering bins stand in the open, without cover of any kind. In cleaning and in tempering, instrumental controls adjust the application of air, heat, steam, hot water, cold water, and inert gas.

In the mill building proper, which is built of reinforced concrete and of four stories rather than the conventional eight, all stocks except the entering wheat and the products of the first and second breaks are con-

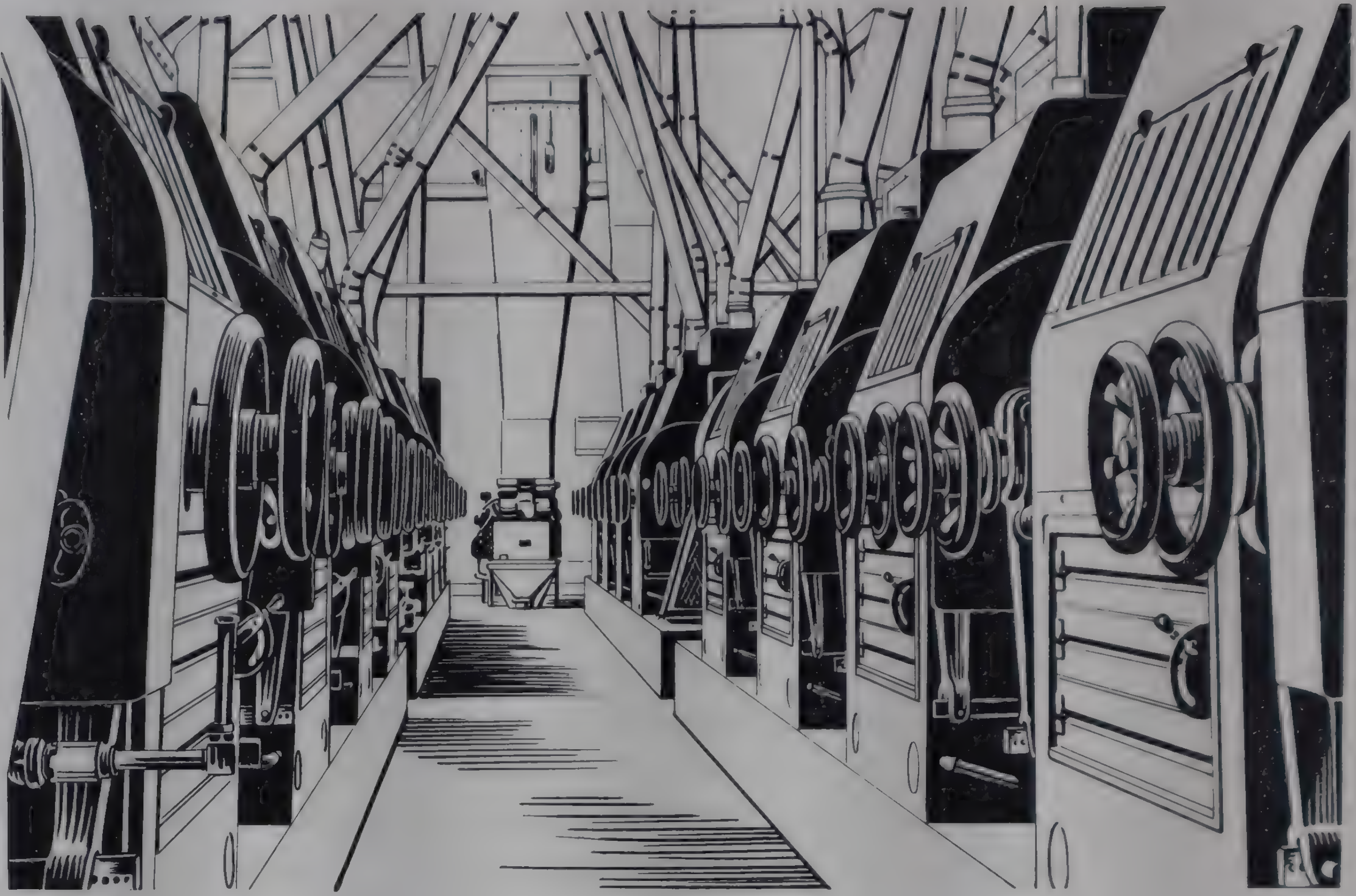


Figure 129. Roller floor of the Los Angeles mill.

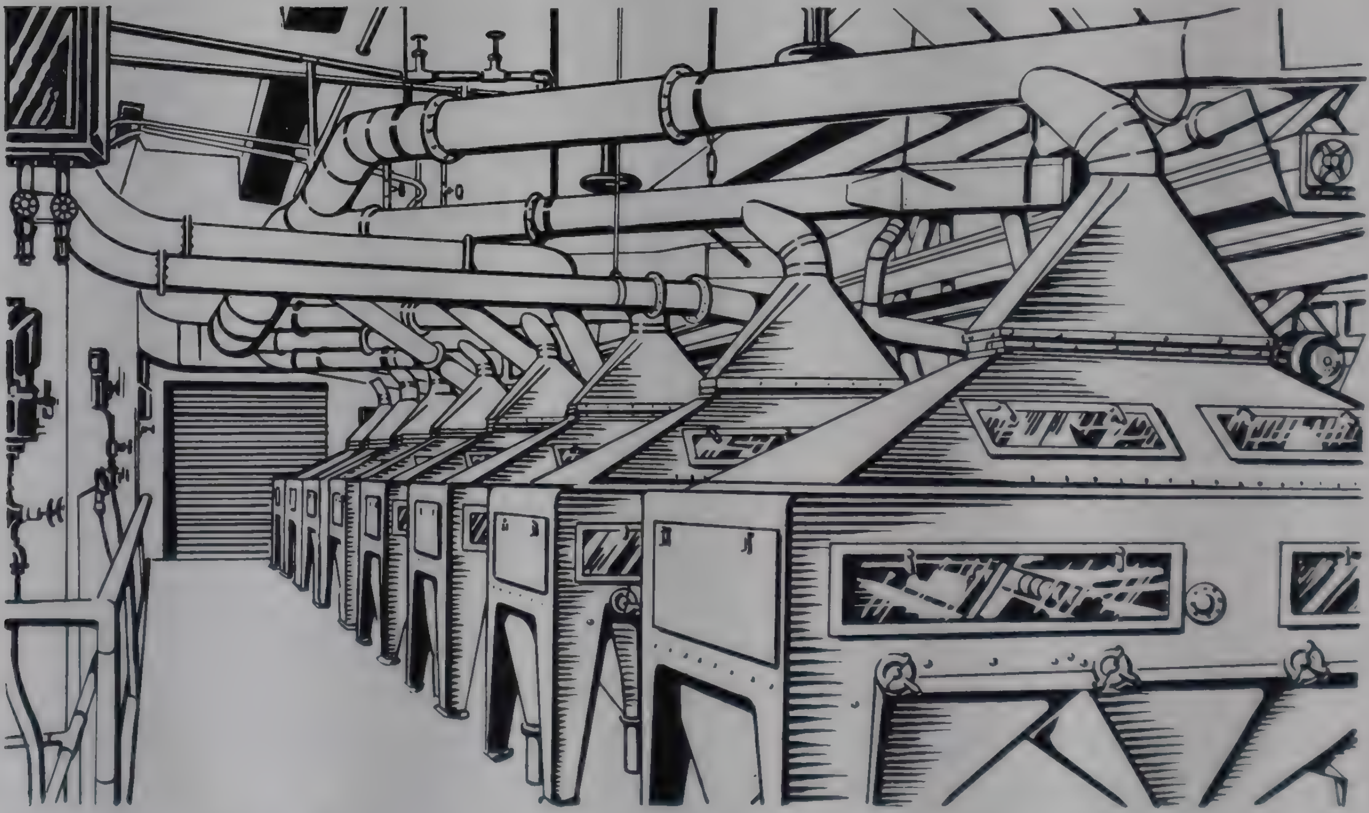


Figure 130. Part of the purifier floor of the Los Angeles plant of General Mills. Note that hoppers under the sieves replace the traditional conveyers.

veyed pneumatically, both horizontally and vertically, through aluminum tubing. The dust-collection and pneumatic-conveying system is operated by machinery located in the open on the roof of the four-story main structure. No cyclone dust collectors are employed, and no reels are used for sifting; the purifiers are of all-metal construction. The machines are powered by unit drives, eliminating shafts and belting; the floor arrangement is similar to that in more conventional mills. Figure 129 looks down on the battery roller assemblies, while Figure 130 shows the purifiers with hoppers under the screens to catch the stock, rather than the conventional conveyers. The entire building is lightly pressurized to prevent outside dirt from entering, and the building itself has no ledges to collect dust, the windows being set flush to the walls. All inside cleaning is done by vacuum.

Tanks that can hold twenty-four hours' production of flour are located in the mill building, physically separated from the packing and shipping section of the plant. As elsewhere, the stock is under instrumental controls, so that it may be properly blended and packed. The packed bags are conveyed to a central station where they are piled on pallets for warehousing or for transportation to a waiting freight car.

Here we see an advance in the milling process itself comparable to the improvement and diversification of its products. Both have been accomplished by the application of modern scientific and technological knowledge, and by the investment of capital on a scale beyond the capabilities of any smaller millers of even the recent past. It is evidence that milling, after its long history of progress, is still a dynamic and evolving art. And it is most convincing evidence that the story is still not ended – that "that which we now do well must be done better tomorrow."

CHAPTER XX

Looking Forward

> No scientific Alexander will ever be able to sigh because of finding no more fields to conquer.
>
> –C. B. Phipson (1900)

Any reader who has followed us through this book must, we think, be filled with a healthy respect for the past achievements of the men who have provided the world with flour for its bread. He has seen how milling has paced other productive activities throughout most of the time since productive activities were first organized, and how, in all periods up to the modern mechanical age, new methods of manufacture usually made their first appearance in the mill: it was no accident that "mill" became the name of any place where things were made. In the betterment of smooth stone tools in those distant days when farmers were first beginning to till the soil, in putting the power of running water or the winds to work, in devising systems of doing automatically what had formerly been done by aching muscles alone – in these and a hundred other ways we have seen how milling has placed mankind in its debt.

All over the Western world, engineering science has revolutionized production in these modern times, and millers were the missionaries of the

Chapter head oval. Man's work and hope act on nature's bounty to make all good things.

new approach. Here in America they took the lead in developing the mass-production concepts that are our special contribution to the world's technology; and by providing an ample supply of wholesome, cheap bread for democratic peoples, the miller and baker have given a solid foundation to mankind's highest hopes. The "breadwinner" today has far more time for winning other things besides bread: whereas a common laborer in 1650 had to work about twenty long days to earn the price of a barrel of flour, a worker in the United States today, even at the bottom of the wage scale, can buy a barrel of far better flour with less than one day's pay.

It is a proud record. But no industry – nothing, in fact, that human beings do – is so perfect that it can advance no further. What are some of the possibilities that lie ahead in man's oldest industry? Having finished with the past and present, it is time for a glance at the future before we close the book.

We can symbolize the history of milling by two opposing cones, placed one above the other and meeting at their points. This pictures the way in which milling began as a broad, crude, undifferentiated activity in which all men were more or less involved, gradually contracted to a highly specialized art operating within a narrow range, and in recent decades has expanded again to a vast complex of productivity touching on our lives at many points. At the base of the lower cone, in the early food-gathering era, every able-bodied man was his own provider and, when seeds were concerned, every family also did its milling. The Stone-Age man used only his grinding stones for crushing his grains and depended solely on the juices and digestive activity of his alimentary canal to assimilate his grist. Very soon he learned to assist his internal digestive processes by the partial predigestion accomplished at the high temperatures of fire – an early example of the dehumanization of functions so characteristic of our climb to civilization. We have advanced as we have found better means of doing things than the meager equipment with which nature provided us.

We can see this dehumanizing process at work as the first cone rose and contracted through progressive specialization. When, much later than the countless ages of primitive crushing between rocks, we first encounter something that can be called milling, it is merely one undifferentiated factor in a food-producing complex that involved agriculture, baking, brewing, even politics and religion. Men might have their special tasks in this activity, but no one stood alone as exclusively miller or baker or brewer, or even priest or king: all shared a mixed responsibility within an involved social pattern.

Slowly over the centuries the priest and king withdrew to exercise their influence over the food supply indirectly, from a distance; and the farmer, the miller, the cobbler, the smith, and all the other craftsmen detached themselves and came to practice their trades independently.

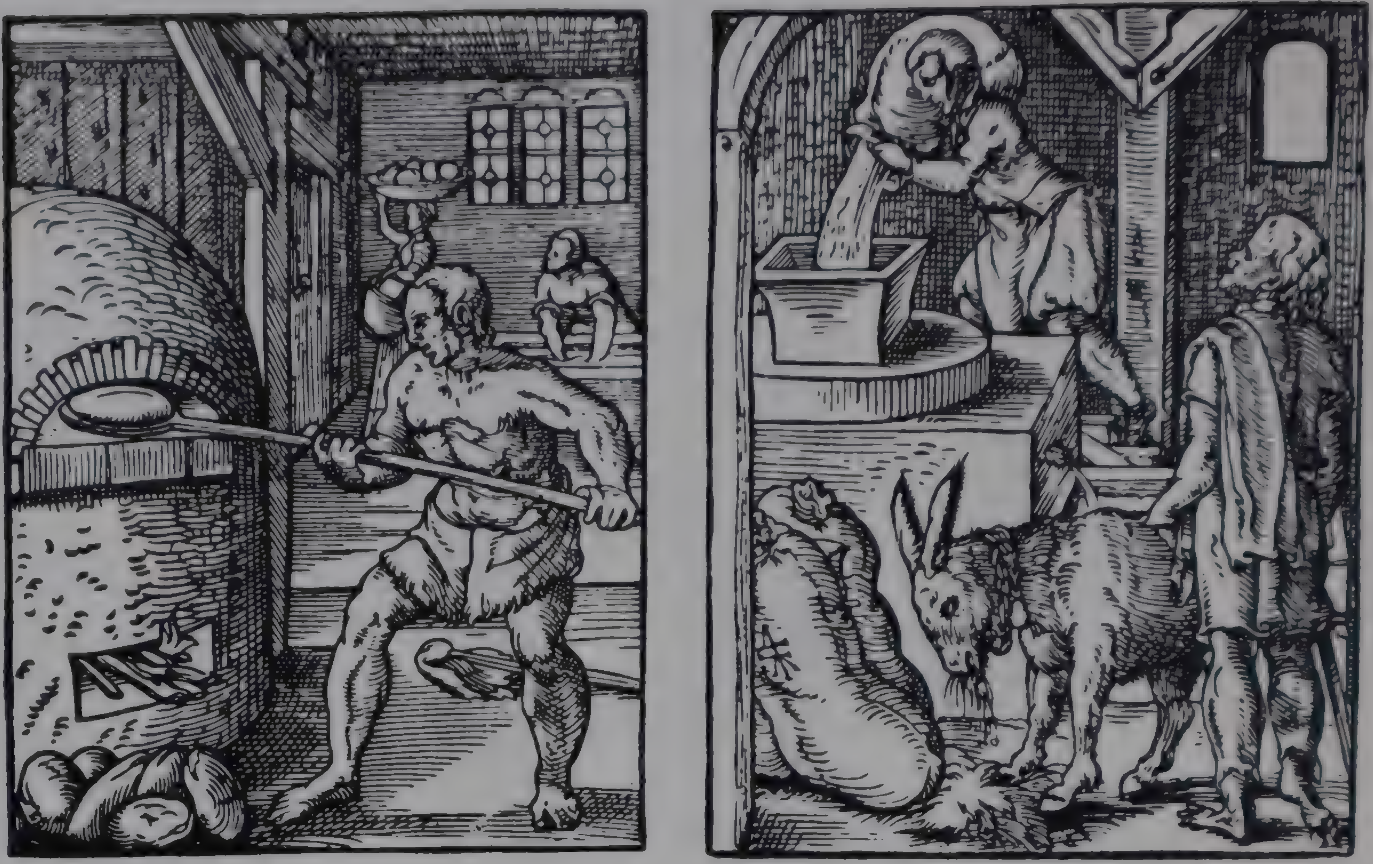


Figure 131. Miller and baker as shown in Jost Amman's *Eygentliche Beschreibung aller Stände auff Erden* (1568). By this time in western Europe, these formerly joined crafts had separated. The pictures give no indication, however, as to which worker was bolting the grist—a function usually performed at that date by the baker.

Baking was last to divorce itself from milling, but during the Renaissance the baker set up in business for himself (Figure 131), buying his meal from the miller and for a time bolting it himself. The construction of mills and especially mill machinery became a specialized trade in the hands of millwrights, and the dressing of millstones became a skilled art practiced by a class of itinerant craftsmen. But the miller, after the mill was built, remained his own mechanic and crude engineer until the nineteenth century, when new specialists appeared to take over these responsibilities. The miller then became merely a flour-maker.

During this process of gradual isolation, the miller's mysterious art became little understood by the general public. In many instances the farmer brought his grain to the miller and received a portion of it back as flour, often without any means of judging the fairness of the division. It is not surprising that the miller became an object of suspicion, and the folk sayings of all European peoples, before the nineteenth century, indicate widespread skepticism as to his integrity. But in the nineteenth century a new kind of miller appeared: instead of remaining a small local tradesman dealing with suspicious neighbors, he rose to the status of a large-scale, progressive manufacturer, respected, like the early Ellicotts, Washburns, and Pillsburys, for the skill and probity he brought to his business. At the same time the wheels of thousands of little toll mills all over the country slowed to a stop, and their picturesque buildings began to crumble into ruins.

The change really began in the late seventeenth century in New York, and shortly thereafter in the Middle Atlantic States, when large supplies of grain from the back country became available, and when large export markets for flour were opened up abroad. Grain had been grown in distant regions to feed large urban populations in Greek and Roman times, but it had always been processed by very simple methods and to meet day-by-day needs, at or near the point of consumption. Even under these conditions the large quantities of grain handled brought about important changes in the craft. With more drastic effect in this country, the influence of greater supplies and new markets led Oliver Evans to develop his pregnant scheme of automatic manufacture. This country was not alone in responding to changed conditions: Hungarian millers carried out a thorough subdivision of processing operations, enabling them to capture distant markets for their excellent flour, and later they introduced the rollers that permit a more versatile and accurately controlled grinding than was possible with millstones.

These achievements were rapidly synthesized in our Northwest in the 1880's, and the processing of grain graduated from its antique status as an art or handicraft, and began to assume the stature of an engineering technique. As the upper cone widened, the mill furnisher became an independent, large-scale producer himself, indispensable to milling. The merchandiser was soon found to be essential, and after him, the advertiser to open doors for the merchandiser. In turn the engineer, the research scientist, the business planner, the economist, and even the social diagnostician took their places in the industry. Today a multitude of professions and trades are ancillary to milling; it has been transformed throughout, and has acquired new obligations, new products, new fields of usefulness, and new opportunities. And still the expanding cone of its activities has not yet reached its maximum diameter.

At first, of course, the significance of the changes was not recognized. For a time the large-scale miller, like many industrialists of a buccaneering era, often prided himself on a "hard-headed realism" which was really a short-sighted opportunism. In the 80's the miller frequently summarized his economic philosophy in the statement that "the best mill is the one that makes the most money." But this slick maxim would soon be superseded by another, less grounded in immediate expediency but more in harmony with the new industrial order then beginning to take shape. This revised rule states that "the best mill is the one that *continues* to make the most money."

There is sound social and economic justification for this definition. In a free economy such as ours we cannot expect progress or even continued good service from an unprosperous enterprise. It is true that a small business can succeed modestly by rendering an unusual service or producing an excellent specialty; but if a product of uniformly high quality is to be made available continuously at low cost to all of 150,000,000 people – whether the product is flour or automobiles – it must be provided by large aggregations of capital which make enough profits to plow back huge sums of money into research, experiment, quality control, plant improvement and expansion.

Competition is the stimulus which continually incites these big enterprises to self-improvement and the extension and betterment of their services; it is the driving force of progress in a healthy free economy. Millers, as well as all other industrialists that were emerging from the craft stage to a modern status as mass producers, had to acquire a new understanding of this truth. They had to learn that free competition does not mean the elimination or even the injury of the competitor, and that the principal reason why monopoly and cartels are antisocial is that they lead to hardening of the business arteries, are inimical to business vigor and progress. Progressive millers were among the first to discern the evils of cut-throat competition and seek the benefits of healthy emulation.

The distinction was clearly put in 1939 by James F. Bell in an address to the Millers' National Federation: "It would be a splendid thing for our company to have some one of you discover a way to make cereal products more acceptable to the public than anything we ourselves have ever been able to produce. We would turn every bit of our energy to equaling you and, if possible, surpassing you. We would all see the best kind of competition, a competition not in low price selling but in goods and services designed to give better values to the public. Out of that competition would spring more buying, a bigger market, more profits for everybody." He goes on to say that the healthy competition for millers is not with other millers, but "with the makers and merchandisers of other types of food; it is with the movie houses and the gas stations, with the milliners and the dressmakers, with everybody, in short, who has something to sell."

For their own welfare, therefore, large concerns in a free economy cannot rest content with satisfying well-established human needs; they must also continually discover and cultivate new services to the society to which they belong. It is not enough to increase the volume of their business; if they are to maintain their strength and health – growth being the only guarantee against decline – they must enlarge the scope of their operations by serving the established needs more effectively or more cheaply or both, and also by finding new needs to satisfy. The style changes of certain modern industries are at best symbols, at worst caricatures, of this injunction to improve continuously, to be forever dissatisfied with the *status quo*, which is laid on industry when it devotes itself to the competitive service of a mass market. Out of this urgency has come the swift technical advance of innumerable American industrial products, from airplanes and radios to chemicals, drugs, and prepared foods, which add incalculably to the possibilities of well-being in the modern world. And it is responsible for the immense strides that the American milling industry has taken, and the vast proliferation of its activities.

These advances in industry require discriminating consumers in constantly increasing numbers to appreciate and support them. It takes an educated, informed, and critical citizenry to recognize and reward excellence even in everyday commodities, and the ratio that these demanding citizens bear to the whole social body must be steadily enlarged. No society frozen in fixed strata could possibly consume the quantities of goods that our machines must produce to amortize the ever increasing capital and labor invested in them, and no such society could support the advances into new fields of production which modern science and technology are continually making. Since markets within our society must grow as production grows, it follows that "supply pursues demand downward through the social structure." This adds up to a steady rise in the standard of living of the average man, and the machines become a most powerful ally of democratic progress.

Progressive millers, along with other industrialists, foresee that the greater part of the road on which they have started still lies ahead. In former days foods rich in starch – the chief energy provider – were the very foundation of the diet; nowadays, among peoples whose standard of living has improved, flour is largely consumed as a carrier of other nutrients. This is the case even with bread, which today usually contains sugar and milk and fats and a whole galaxy of added vitamins, in addition to the water and leavening and salt of former days. It is not reasonable to expect people to consume as much flour as they used to, along with their more varied diet of today. Among peoples living on diversified diets, therefore, the miller must increase the acceptability of his products or get a smaller share of the consumer's dollar.

Bread itself is an opportunity for more skillful catering to the taste buds. Most of the bread consumed by Americans today is commercially baked, and while this bread is pure, nutritious, and long-keeping, it still has not reached its ultimate capacity to satisfy our palate: it lacks the appeal of that increasing rarity "home-made" bread. This is certainly true so long as a writer like Dorothy Thompson can describe commercial bread, however unfairly, as "a sickly, bleached-blonde, airy, quick-staling, crustless, sweetish, sticky mass," which is "low in sensory pleasure." And it is given striking proof by a survey of 239 Army camps and stations in the United States, made during World War II by the Quartermaster Corps, which showed that the daily consumption of commercial bread was 0.280 pound, while the quantity rose to 0.313 pound when Army-baked, or "home-made," bread was supplied. The Army bread was made by the straight-dough method, as distinguished from the sponge-dough method used by our commercial bakers, and the soldiers found it more compact and flavorful. This improvement in flavor is obtained by longer fermentation at lower temperatures than is common with bakery breads, and by the use of more yeast.

The improvement of commercial bread is not the responsibility of bakers alone, since it may require flours different from those now available. Here is a field of progress in which millers may well take the lead. If they can increase the palatability of bread, into which the bulk of their product still goes, as it always has, they will increase their service to society and at the same time expand their own business. It is in this way that continued commercial success in a free competitive society is achieved.

The hidden values in the wheat berry are of two kinds, and the exploitation of neither kind is complete as yet. First there are those nutritive properties and taste characteristics that can be embodied in bread and other food products — pastries, cereals, special breads — and while a great deal has been accomplished in this direction in the past half-century, the millers' research staffs and experimental kitchens are busily exploring new possibilities, and there is every probability that the future holds many delightful new sensations for our palates, to be gained from new cereal products. This is a field of service not to be underestimated: even cattle benefit from a change of pasture, although the grazing may be no more abundant in the one field than in the other; and we have come to realize that variety and gustatory appeal in our diet are not only pleasant but immensely beneficial.

The other type of values in the wheat berry, not yet fully exploited, is more purely chemical. The miller can think of himself as dealing with certain cereal grains of known properties, which can be processed into a series of accepted foodstuffs; or he can think of himself as dealing with an industrial raw material, a form of matter and energy (themselves one) organized by nature in certain ways, but capable of reorganization in many other useful ways. In fact, we are beginning to regard all products of the soil, from potatoes to sugar cane, not as merely foodstuffs but also as the raw materials of chemistry. A cereal grain is a collection of various kinds of molecules, which can be separated and rejoined in new combinations; the atoms within the molecules can be rearranged to form molecules of different characteristics; and even the much smaller nuclear and electronic constituents of the atom are rapidly coming under man's control.

A field of unknown extent opens for exploration as the miller comes to regard himself not merely as a grinder of grains but as an industrial chemist. His guide will be his careful estimate of relative values: what can he do with his class of raw materials — the cereal grains — that will render them, and all parts of them, of greatest value to society? Many beginnings have been made, such as the large-scale production of industrial starches and glutens mentioned in the preceding chapter. During the war, with molasses in short supply, granular wheat flour was manufactured to make industrial alcohol for use in such unlikely end-products as synthetic rubber and explosives. We cannot foresee the limits of these possibilities in an age that is making lacquers, perfumes, and nylon from coal, air, and water, extracting magnesium from sea water, and extracting oil not only from shale but from old cornstalks and dry leaves.

Again, the possibilities of a scientific revolution in the processes of milling itself have not been exhausted. The separation of bran and endosperm is accomplished today almost wholly by mechanical means, with remarkable success but with a vast complication of low-energy machines which are direct descendants, greatly improved, of the ancient millstone and sieve. These two primitive implements have had a bewildering progeny, but the original processes of grind and sift, grind and sift, however much they may have been refined, are still the source of our best white flour. The very complexity of the modern mill raises basic doubts of its technology, in the light of our modern adherence to Occam's rule that no way can be final if a simpler, less complicated route to the same end can be found.

Now that chemists and physicists are firmly entrenched in the milling industry, and have proved their powers by important contributions in the phases of conditioning, bleaching, and enrichment as well as the development of new products, it is quite probable that in attacking the basic problem of separating bran from endosperm they may come up with some wholly new, nonmechanical method of accomplishing it. What this may be cannot be predicted in advance of the event. It is significant that in the production of flour no important use is made as yet of high pressures, high vacuums, explosive actions, or high-frequency radiations, which play so large a part in modern chemical industries. The future may see us opening up the wheat berry by some such means, and dividing it neatly into its components without a single roller or sieve being involved.

This possibility attracted the efforts of a few investigators, long before they were equipped with adequate scientific knowledge. In 1871 Sazille in France developed a process for dissolving out the starch from wheat to make bread dough directly, without any grinding or sifting. The catch was that it took twenty-four hours to make the dough, and the resulting bread was very poor stuff. Others succeeded in shortening the process, but not in improving the bread. By 1904 the Apostoloff system was being tried in Great Britain, whereby wheat berries were broken and some flour made on steel grinders like millstones, and then the rest of the endosperm was dissolved out and separated from the bran. Again the process worked, but nobody liked the bread. In 1940 the Continental Baking Co. sponsored a flotation process of making whole wheat flour, invented by Theodore Earle, a mining engineer. The grain is churned about in a series of tubs filled with water to which a bubble-forming detergent is added. The bitter outer coating of bran, or "beeswing," is peeled from the wheat and carried to the surface by the bubbles, and then the peeled wheat is dried and pulverized by hammer mills, to make the flour of a brown but palatable bread. The same flotation process can be used to clean wheat before grinding it by orthodox methods. In 1941 Tage Jensen Klint of Denmark patented a wet grinding method, in which the grain after cleaning and steeping is worked into a paste, and then spray-dried to a powder so that the branny parts may be sifted out. The claim for this process is that it preserves more of the vitamins of the berry. In Germany experiments have been made with a wheat-conditioning machine that prepares the hardest wheats for grinding by exhausting air from the kernels by vacuum and transferring them to a water bath, where the endosperm is mellowed in ten minutes.

None of these methods is a wholly new approach to flour-making, and none produces a wheat flour as acceptable as that now being made by the delicate but laborious operations of the conventional modern mill. They indicate, however, a keen interest in the possibility of discovering a short cut. This may be accomplished by one of those excursions in research which cannot be directed and can only be followed to unpredictable results, just as Dr. Carothers, when he began working with coal in search of long polymer cells, had no idea that his work would produce, among many other things, sheer stockings for the legs of millions of women and small molded gears of precision machines.

Quite aside from the possibility of revolutionary scientific advances within the milling industry and its products, there exist huge opportunities for its external expansion. Wholesome white bread at low cost is so much a matter of course to most of us here in America that we forget the segments of our population which still do not obtain an adequate ration of this basic foodstuff, to say nothing of such commonplace luxuries as pastries and breakfast cereals. As the standard of living we like to think of as typically American spreads downward through our economic pyramid, the miller's potential market automatically expands: like all mass-production manufacturers, he has a direct stake in the broader dissemination of economic prosperity. But the opportunities here are small compared to those that exist in the rest of the world. Without any impetus from mere idealism, American millers may have their share in the most urgent business now before mankind—the business of raising the standard of living of the vast backward populations of the world, so that they too may become fertile fields for the spread of freedom and enlightenment.

Millers are fortunate in that they do not have to create an initial liking for wheat flour. For thousands of years its blandness and adaptability have caused Western man to prefer it above all other sources of life energy. We can assume confidently that this same liking exists, potentially, among the many millions of the world's people who have never had an opportunity to gratify it. Those to whom white bread would represent a great step upward in well-being far outnumber those now being served; and this is still true even if we discount the Oriental populations whose needs are served by rice rather than wheat. It is well to remember, however, that much more wheat than rice is consumed even in northern China. Trade between industrialized peoples probably will be subject to restrictive regulation for a long time to come. But the nonindustrialized peoples of North and South America, Africa, the Near East, and many other parts of Asia constitute an opportunity for the miller's intelligent self-interest – the only reliable motivating force behind human progress – to work for his own and the world's benefit.

The world we now live in has been so largely created by man's efforts that we can no longer be sure which of the limits still set on our activities are insurmountable, and which will fall before the ingenuity of the future. As Garet Garrett has said, "That change which alone sets our time off abruptly from all time before is the fact of potential plenty." The miller already has played a great part in establishing that fact of potential plenty. We can foresee his service expanding into new fields: through research into more varied uses of the nutritive elements in cereal grains and the further exploitation of their chemical properties; possibly through radical changes in the milling process itself in the direction of greater simplicity and economy; and through his cheap and wholesome products' being made available to the vast numbers who still live in the primitive stages of grain utilization. These are immediate possibilities: but unquestionably there are countless others, at least equally pregnant, which we cannot foresee.

We have come a long way from the dawn man who gathered the seeds of wild grasses and crunched them between his molars or ground them between two stones. We cannot tell what eras of unimaginable plenty and well-being still lie before us. We can only be sure that the story of milling has many chapters yet to be written; and we must wait until the future unfolds them, confident that they will be as profoundly significant in the record of human progress as any that can now be read.

REFERENCE MATTER

Vocabulary of Milling Terms

Aging. In former days a step in the milling process by which flour was allowed to stand for a considerable period after grinding until its original creamy color turned white. This process improved its appearance and quality. At the present time the same result is obtained by chemical bleaching.

Air-belt purifier. One in which little or no air is drawn from outside the machine, the same air recirculating through the sieve and fan. Such machines require very efficient dust collectors.

Aspirator. A machine which blows air through a stream of grain to clean it of lightweight particles.

Backbone. The principal ingredient of a flour blend.

Bakers'. Former name of first clear flour.

Balancing. Adjusting the operations of the various breaks and separations in a modern roller mill to produce a desired result. In millstone milling, setting the runner stone over the bed stone so that it runs true.

Beard. The small hairs that grow from one end of the wheat berry.

Bed. In dressing millstones, the three lines running across a stone, forming an equilateral triangle, which were first trued to each other, in order to form base lines for trueing the entire surface of the stone.

Bed stone. The stationary (lower) stone of a pair of millstones.

Beeswing. The two outer layers of the bran coat of the wheat berry. So called because of their cross markings and texture.

Berry. A grain of wheat.

Bolting. Sifting or dressing. This term is less used abroad than here, where it usually refers to the action of a centrifugal.

Bosom. The area immediately surrounding the eye of a millstone. In a stone built up out of smaller pieces cemented together, the bosom includes the first circle of pieces around the eye.

Brake wheel. The large wheel on the inside end of the main shaft which, rotated by the sails or mill wheel, in turn drives all the active parts of the mill. A brake band could be applied to this wheel to control the rotation of the millstones.

Brass. The renewable lining of a bearing, which takes the wear of friction due to turning.

Break. Any one of the roller-grinding processes by which the grain is reduced to flour. The first break begins the process, and is followed by the second, third, etc.

Breast wheel. A water wheel in which the water reaches the buckets on the circumference of the power wheel at about the middle of the wheel or just below. The wheel is therefore turned in part by the impact of the water, and in part by its weight.

Brush. Same as *Beard.*

Burrs (*Buhrs*). Used generally for millstones, especially if composed of sandstone, and more particularly for the type of stone mined in the Marne Valley near Epernay, which was greatly preferred for its superior grinding qualities.

Cap mill. A windmill whose sails are faced into the wind by rotating the top of the mill, in which the windshaft is set, rather than by turning the entire mill structure. The cap is usually geared to the curb or top of the mill tower, and can be turned into the wind either by hand or (in later developments of it) automatically by means of a fantail.

Centrifugal. A rotating bolter in which the ground material is forced against a circumferential sieve by rotating beaters as the sieve also rotates.

Chill. The hardened (external surface) portion of a chilled-iron roller.

Chop. The product of a break in a roller mill or (in former days) of a millstone grind.

Chunk. A particle composed mainly of bran, but with some floury material attached. Produced when roller corrugations are too sharp and differentials too great. The opposed danger is too much break flour.

Clears. The coarser parts of a straight flour. Some mills formerly turned out as many as four clears—first, second, etc. The finer parts are patents.

Concert chest. Old name for a chest of reels; so called because the reels were driven *concertedly* by a chain of spur gears.

Conditioning. Controlled moistening of grain to prepare it for grinding by toughening the bran and mellowing the floury part of the berry. Usually synonymous with *tempering*, but sometimes used to cover specifically the process of wetting different wheats to bring them to the same condition for grinding.

Contract wheat. Wheat conforming to a specified government standard.

Cover. A screen through which stock is sifted.

Cracking. Cutting the surface of a millstone with closely spaced fine lines, between the furrows, to assist grinding.

Crown-tree. The large crossbeam resting on the support post of a post mill, and making a base for the mill structure.

Curb. See *Cap mill.*

Cutter roller. The more rapidly rotating of a pair of rollers.

Cut-off. An adjustable dividing board located under a sieve so that the miller can change the flow of the stock to get the best possible result as grinding and sifting conditions change. "To shorten bolt" was to draw off less flour, "to lengthen bolt" was to draw off more. Also the term applied to the closing out and measurement of transactions as of a certain period.

Cut straight. A straight flour from which a (better) part has been removed.

Damsel. The device which agitates the hopper, as the upper millstone revolves, so that grain is shaken down into the eye of the stone for grinding. It may be no more than a weight attached by a cord to the base of the hopper, which rests on the upper stone and is jiggled by its rotation. Or it may be an attachment to the top of the shaft, which runs up through the eye and knocks against prongs at the lower end of the hopper.

Differential. In roller milling the ratio of rotation of the fast and slow rolls.

Disc separator. A machine containing a set of upright revolving discs covered with small pockets; it is used in wheat cleaning to separate the foreign matter from the grain.

Draft. The degree to which a millstone furrow departs from the radius of the stone by starting from one side or the other of the stone's center.

Draft circle. The circle around the eye of the millstone from which the furrows run tangentially. The furrows are located in terms of this circle, rather than in terms of the center of the eye, in order to give the proper cutting action. The larger the draft circle is, the more quickly will the stock be carried to the circumference of the stone.

Dress. To sift or bolt. To true the surface of a millstone and cut lines in it, with a view to improving its grinding capacity.

Dressing. The scalping off of oversize particles from a flour stock.

Dull-to-dull. Term applied to the operation of roller mills when they are so run that the *longer* face of the corrugated cutting edge on the faster rotating roller meets the *shorter* face of the edge on the slower rotating roller. The more usual method of grinding in the United States. Called in England "back-to-back." See *Sharp-to-sharp*.

Dunst. Small middlings from which all the bran has not yet been removed. Dunst will pass through a No. 8 or 9 silk, but not a No. 10 or 11. Comes from "dusty middlings." In more common use in Britain than in the United States.

Dust middlings. See *Dunst*.

Dusting. Separating flour from middlings, especially so that the latter may be more successfully purified.

Edge-block stone. One arranged to grind on the grain of the stone. The grain is perpendicular to the grinding surface, as in a cross section of a log. This type of stone tends to be sharper, but more liable to crack, than a face-block stone.

Ending. The process of running wheat between millstones, usually held somewhat fa apart on stiff rynds, to rid it of adhering dirt, beard, outer skin, and some of the germ. For best success the wheat was sized and each size sent to an appropriate stone.

Extraction. Percentage of product obtained, as measured against the gross weight of the raw material. *Extraction of 72 per cent* means that for every 100 pounds of wheat used 72 pounds of flour are obtained. The remaining material, less that lost in cleaning and in processing, goes into animal feed.

Eye. The central opening of a millstone. Sails are said to be *set in the eye of the wind* when they stand in a plane at right angles to the wind's direction.

Face. The level surface on a millstone, between the furrows.

Face-block stone. A millstone cut so that the grain of the stone lies lengthwise to the grinding surface—like a log laid on its side.

Facing. Trueing the surface of a millstone.

Fancy patent. A very short patent flour; under, say, 60 per cent of the total produced.

Fantail. A small control sail wheel, invented by Meikle, set at a right angle to the main sails of the mill. It rotates until it lies along the line of direction of the wind, and thereby turns the main sails into the eye of the wind.

Feather edge. The more gently sloping edge of a millstone furrow.

Filler. A flour added to a blend to provide bulk rather than strength.

Flake. One of the particles composing feed bran; also a particle of middlings material that has flattened out during grinding.

Flake-buster. A machine to break up middlings flakes.

Flow sheet. A chart indicating the machines involved in a milling operation and their functional position in a sequence of operations. The flow of material from machine to machine is also indicated, as well as what happens to it at each point.

Furrows. The grooves or channels cut in the face of a millstone.

Grading. The tendency for the flow of grain from an uncontrolled storage bin to separate according to weight. The light grains tend to settle near the bin wall on filling, and the heavy grains tend to leave the bin first. Can be corrected by appropriate exit arrangements.

Gradual reduction. The modern process of milling, in which the aim is to produce middlings rather than to avoid doing so, as was true before the New Process. The middlings are graded and separated from the bran (so far as possible) by sieves and purifiers, and each size is retreated according to its need. The same process is repeated until the desired end products are secured.

Groats. The berry from oats after removal of the hull.

Half-high grinding. See *New Process.*

Head of the mill. That part of the mill where the initial processes take place.

Head sick. Said of a post mill which is unbalanced so that it leans forward.

High milling. Grinding with the millstones (or rollers) widely separated. A number of grinds become necessary. The aim is to produce partially ground materials in the first grind which will yield more or better flour in succeeding grinds. Similar to *New Process.*

Holding roll. The less rapidly rotating of a pair of rollers.

Hopper boy. An invention of Oliver Evans; it spread out freshly ground flour for cooling, and then gathered it together again for packing.

Households. A type of flour for family use. Now obsolete.

Hungarian process. The modern system of gradual reduction with rollers and primitive purifiers was so called in the early days of roller milling, because it was first rendered practical in Hungary.

Land. See *Face.*

Lantern. A variety of wallower in which the gear members are vertical wooden staves, held at the top and bottom by solid wooden discs. A lantern pinion looks like a round cage or lantern.

Long patent. One including a relatively large percentage of the finest flour; around, say, 90 per cent of the total flour being produced.

Long system. One involving a relatively large number of reduction processes, leading to a large number of differentiated products; there may be fifteen or more.

Low milling. Grinding with the millstones (or rollers) close together. This method of grinding was in general use before the New Process. The aim was to produce as much flour as possible at one grinding. In *high milling* the later grinds are successively lower.

Mettle, to show one's. Derived from *metal*, referring to small bits of stone which became embedded in the millstone dresser's hand, where they showed as blue specks. "To show one's metal" meant to demonstrate that one was a qualified stone dresser, a highly skilled profession. It therefore came to mean "prove one's skill," with overtones suggesting the demonstration of courage.

Middlings. Coarse bits of the floury part of the wheat berry, with which small bits of bran may still be associated. In a very different meaning, usually as either *standard middlings* or *flour middlings*, it refers to fairly high grades of animal feed.

Middlings rolls. Those rolls whose operation produces mainly middlings. Usually called reduction rolls in England.

Mill-mix. Mixture of several types of wheat to produce a desired flour.

New Process. The process of high grinding, with one or more lower regrinds, that came into use in the United States just before the introduction of modern roller milling. In comparison with very long continental systems, those favored in the United States were sometimes described as "half-high grinding."

Nip. In a roller mill the minimum distance between the corrugations of the rolls as the latter rotate.

Offal. Older term for that part of the grind which goes into feed – called feed or millfeed here, and wheatfeed in England.

Overdrift. The term applied to a stone if the spur wheel drives it from above.

Overshot wheel. A water wheel in which the water reaches the buckets on the circumference of the power wheel at the top of the wheel, by means of a flume. The wheel is therefore turned by the weight of the water.

Over-tails (*overs*). See *Tailings*.

Patents. The better (finer) parts of a straight flour, made entirely from purified middlings. Some mills formerly turned out as many as four patents – first, second, etc. – corresponding to the appropriate *clears*. Called *patents* because they were first produced by patented methods.

Pelican. A spout sampler for obtaining a representative sample of a falling stream of bulk grain.

Plansifter. A machine in which a number of oscillating sieves arranged one above the other are used to separate the grind for further milling.

Pony. In New-Process mills the smaller pair of millstones that were sometimes used to grind the middlings.

Post mill. A windmill in which the entire mill structure must be rotated to face the sails into the wind. The mill structure stands above the ground on a support post.

Proving. The second rising of bread dough, after it has been scaled-off into loaf-weight pieces.

Purifier. A machine in which an air current blown up through middlings dancing on an oscillating sieve is used to separate them from the free bran with which they are associated. The middlings are then ready for a finer grind.

Red dog. Very low-grade, branny flour, suitable only for animal feed. Seldom used outside the United States. Said to have been named from an Indian who used it.

Reduction. The process of milling grain into flour and its by-products.

Reel. A rotating, generally cylindrical sieve, without beaters inside.

Release. The amount or percentage of stock from a break which does not go to the next break, but is sent to purifiers, bran dusters, etc., for grading.

Returns. Stock which is sent back for retreatment to the same machine – bolter, purifier, roller assembly, millstone, etc. – or even to a machine nearer the head of the mill.

Ripeness. Readiness of dough for baking.

Roller system. The modern method of reducing wheat to flour, utilizing a number of pairs of facing rollers to break and reduce the grain, along with purifiers, sifters, cleaners, dust collectors, packaging machines, etc.

Rule of thumb. The phrase derived from the old-fashioned way of testing the quality of the grind, between the miller's thumb and first finger.

Runner. The upper (rotating) stone of a pair of millstones.

Run with (against) the sun. Said of a millstone which has its furrows cut so that the runner stone rotates in a clockwise direction, as one looks down on it.

Rynd. The crosspiece in the eye of the upper millstone by means of which it is supported on its shaft. Balance rynds allowed the upper stone to adjust to the lower in grinding; stiff rynds held it firmly in a plane parallel to the lower stone.

Scaling-off. Separating dough into loaf-weight pieces.

Scalp. To sift, and especially to sift off the coarsest portion of the grind; also used for the removal of foreign matter from the grain before grinding. (A word of all work.) When *scalping*, *grading*, and *dusting* are distinguished, the first refers to the separation out of material for return to break rolls farther along in the system, the second to separations for the reduction rolls, and the last to the separation of flour. All these separations may go on concurrently in the same machine.

Scratch rolls. In England finely fluted rolls whose function is to remove bran fragments from the floury middlings.

Scroll. See *Flake-buster.*

Semolina. Large middlings, dressing through from 18 to 40 meshes per inch; more specifically, the purified middlings of durum wheat, used to manufacture macaroni and spaghetti.

Sharp-to-sharp. Term applied to the operation of roller mills when they are so run that the *shorter* face of the corrugated cutting edge on the faster rotating roller meets the *longer* face of the corrugations on the slower rotating roller. This is the more usual European method of grinding, called in England "front-to-front." See *Dull-to-dull.*

Sharps. Middlings.

Shoe. Frame of the sieve used in a scalper. In millstone days the piece below the hopper container which was agitated to serve grain continuously between the stones.

Shipstuff. Old name for low-grade, high-bran-content flour.

Short patent. One including a relatively small percentage of the finest flour; under, say, 80 per cent of the total flour being produced.

Shorts. A low-grade flour, containing principally germ and fine bran. Used for animal feed. A similar product is known now as *wheatfeed* in England. See that term for synonyms, some of which may be in use here.

Short system. One involving a relatively small number of reduction processes, leading to a small number of differentiated products.

Sifter. A bolter, especially one in which horizontal sieves are used, as distinguished, for example, from a centrifugal.

Sizing. Breaking down and grading the coarser middlings (semolinas).

Skimming. See *Facing.*

Skirt. The outer portion of a millstone, beyond the bosom.

Slicking. Smoothing out a sample of flour for comparison with a standard as to color, etc.

Smutter. Formerly a general name for any wheat-scouring machine. Now confined to a machine designed to rid the grain of smut.

Sprattle box. A device for throwing a millstone out of gear, so that it will not continue to rotate.

Spur wheel, great. See *Stone nut.*

Stone. A millstone; often used in such phrases as "a mill of six run of stones."

Stone, flowing of. Those parts of the surfaces of the millstones, near their rims, where they are in close fit.

Stone nut. The small pinion (gear) by which a millstone is driven. In a single-pair mill, this would be the same as the wallower. Where there is more than one pair of stones, the stone nut for each pair must stand on a separate shaft, geared to the main shaft (holding the wallower) through the great spur wheel.

Straight flour. All of the grind that is intended for human consumption – everything, that is, except feed. It can be divided into a number of grades – *patents* (the best) and *clears.*

Strength. The ability of a flour to produce bread of satisfactory shape, texture, and appearance. This depends on the quality as well as the quantity of protein in the wheat.

Strengthener. A wheat which is added to another wheat to improve the quantity or quality of its protein content.

Stuffed straight. A mixture of a straight flour from one grind with a first clear from another grind.

Swallow. Alternative name for the millstone eye; apparently confined to England.

Sweat. The changes in wheat induced by moisture and heat, as in tempering or during storage. When properly controlled, these changes amount to a partial beneficial fermentation.

Tailings. The material that leaves a bolter or sieve at its far end, because it is too coarse to pass through it.

Tail of the mill. That part of the mill where the final processes take place.

Tail post. In a hand-turned windmill the downward projecting post whereby the sails are turned to face the wind.

Tail sheet. A coarser sieve at the far end of a dresser (sieve), designed to scalp stock coarser than the material sieved through the rest of the dresser.

Tail sick. A post mill which is unbalanced so that it leans backward.

Temes. An old word for sieve. See also *Thames.*

Tempering. See *Conditioning,* with which it is identical in general meaning. When the two are distinguished, *tempering* has to do with preparing a homogeneous batch of grain for milling, while *conditioning* has to do with preparing wheats of different kinds so that they can be ground together.

Tentering. Adjusting the distance between the millstones so as to give a higher or a lower grind.

Terminal velocity. That rate of aspiration, usually stated in feet per minute, which is just sufficient to lift a given type of particle from a mixture.

Thames, to set the, on fire. A corruption of the phrase "to set the temes on fire," *temes* being an old word for sieve. The temes was constantly agitated by a boy. Since the mechanism was made of wood, too energetic movement might set it on fire. The phrase is used negatively ("will never set the Thames on fire") to signify a person lacking in energy.

Throughs. The material that passes through a bolter or sieve.

Thumb, miller's. A phrase arising from the fact that through much testing of his grind the old miller's thumb became flattened. Some held, however, that it got this way by being pressed against the weighing scale.

Top. An extremely short patent; perhaps as little as 20 per cent of the total flour being produced.

Tramp iron. Bits of metal mixed in with the grain as it comes to the mill. A magnetic separator is required to clean it out.

Trundle wheel. A variety of wallower in which vertical pegs held in a single wooden wheel take the place of the staves of the lantern. Such wheels were larger than the lantern pinions they replaced, and the pegs were shorter than the staves.

Twist. A term to designate type of weave. In half-twist cloth every alternate warp, and in full-twist every warp, consists of two half-size threads, one passing over the woof and one under, to lock it securely in place so that the meshes will not become irregular.

Underdrift. The term applied to a stone if the spur wheel drives it from below.

Undershot wheel. A water wheel in which the water reaches the buckets on the circumference of the power wheel near the bottom of the wheel. The wheel is therefore turned only by the impact of the water.

Wallower. The first driven wheel of a windmill or water mill. In a mill with a single pair of stones, it is found on the drive shaft of the upper millstone. Where the mill has more than a single pair of stones, it stands on the shaft which drives the stones through the great spur wheel.

Warbler. The clapper or bell in old mills which automatically sounded when the hopper was empty, to prevent the millstones from running empty.

Weakness. A wheat is weak when it fails to produce bread of satisfactory shape and texture. This is due to the quality as well as to the quantity of protein in the wheat.

Wheatfeed. English name for a low-grade flour, containing principally germ and fine bran. It includes what was formerly called by such names as sharps, pollards, parings, toppings, seconds, thirds, weatings, randans, or gurgeons.

Whizzing. Whirling grain in a centrifugal machine to rid it of surplus water added during cleaning.

Windshaft. The shaft on which the sails of a windmill are set.

Yield. A unit of finished product expressed in terms of the number of bushels of grain required to make it.

References and Notes

What follows is an informal and representative rather than an exhaustive and full-dress list. It includes only a small part of the material we have used in writing our history. A fairly complete bibliography of milling would require many volumes, and a full justification of every statement in our text would occupy much more space than the items themselves. Many useful titles were not listed because they appear in bibliographies specially noticed in the references cited; and we have not given authority for information that is common knowledge to those familiar with the subject or generally accessible to the interested.

Students are warned against the many errors in the sources cited. We have not indicated the thousands of minor decisions as to dates, places, names, spellings, characteristics of machines, arrangements of processes, etc., that were forced upon us during our work. The history of technology is at present chaotic. It would need a genius with great selecting power—or perhaps a multitude of such geniuses—to make it a thing of order and beauty.

The references are grouped by chapters, although not all of them keep within these boundaries. We have included two general lists—one at the beginning to cover the entire subject, and the second after the references for Chapter X to cover modern milling. We have allowed ourselves but few duplications; those interested in a particular topic should run through pertinent parts of the entire bibliography for germane materials if they wish a more complete view of some matter.

Most magazine articles are listed without title or author. The abbreviation *JRAI* has been used for the *Journal of the Royal Anthropological Institute of Great Britain and Ireland.* Other abbreviations will be readily understood.

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CHAPTER VII. MILLING BECOMES A BUSINESS

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CHAPTER VIII. WATER TURNS THE MILLSTONES

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CHAPTER IX. MAN MASTERS THE WINDS FOR MILLING

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CHAPTER X. MAN'S NEW POWER RESOURCES

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(The quotation from Plato in this chapter is from the *Republic* 7.525.)

GENERAL REFERENCES ON MODERN MILLING

Though a number of technical books have been included in the bibliographies that follow, for the most part only articles of historical interest have been listed. Technical articles are too numerous for citation, especially in recent years. Even the sixty-page *Bibliography of Cerealiana* published in 1938 by the *Northwestern Miller* contains few technical listings from milling journals, being confined largely to material appearing in national and state publications. For up-to-date presentations of milling machinery and systems of milling, the reader should consult current and back issues of *The Consolidated Grain Milling Catalogs,* published annually by the *American Miller*; also, during recent years, the monthly special Production Number of the *Northwestern Miller.* The trade literature of mill furnishers listed in these publications is also of interest. *The Miller's Almanack and Yearbook,* issued since 1909 by the *Northwestern Miller,* at first as a separate booklet but now as a special April issue, contains statistics of the world's production and consumption of grain and grain products, surveys of laws and regulations of interest to millers, and items curious and important relating to the industry. Every few years the *Northwestern Miller* publishes a special issue which lists all known American and Canadian mills.

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CHAPTER XI. MILLING COMES TO AMERICA

Indian Practices

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CHAPTER XII. OLIVER EVANS INVENTS THE AUTOMATIC MILL

Oliver Evans

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American Miller, 11:535, 584 (1883). On French bolting systems.

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Beckmann, Johann. *Op. cit.,* p. 258.

Magasin pittoresque, 20:54 (1852). Types of flour produced.

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———. 9:238, 289 (1880).

———. 15:397, 548 (1887).

Northwestern Miller, 16:182 (1883).

———. 25:688 (1888).

———. 51:289, 309, 337, 357, 384, 405 (1901).

———. Vol. 192, Production Number, Oct. 13, 1937, p. 43. On modern practice.

(The source of the chapter head oval of Chapter XII is *Northwestern Miller,* Vol. 196, Nov. 23, 1938, p. 10.)

CHAPTER XIII. WESTWARD HO!

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Bidwell, P. W., and J. I. Falconer. *Op. cit.* (Source of the following materials: pp. 277, 279, 321, 332, source of our Figures 78 and 79; p. 152, of population statistics cited; p. 162, of chapter motto from Faux; pp. 174, 309, data on New Orleans trade; p. 210, plow patents; p. 310, Buffalo receipts during 1836 and following years.)

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Manchester, H. H. "When Oswego Wore the Milling Crown," *Northwestern Miller*, Vol. 190, June 23, 1937, p. 50.

Northwestern Miller, 44:765, 782 (1897).

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———. 23:126, 202, 275, 346, 533 (1895).

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———. Vol. 234, June 1, 1948, p. 7.

Miscellaneous

American Miller, 16:537 (1888). On first electric flour mill.

American Nation Series, Vol. 14. (P. 103, material on 1822 Ohio trade; p. 134, source of chapter motto from Turner.)

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Clark, V. S. *Op. cit.* (Vol. 1, p. 259, effect of repeal of Corn Laws.)

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CHAPTER XIV. AUTOMATIC MILLING AND THE PURIFIER START A REVOLUTION IN AMERICAN MILLING

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199, August 30, 1939, p. 24. On Fife wheat. For other references on Fife wheat, see Chapter XVII.

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Swanson, C. O. "The Flour Particle," *Northwestern Miller,* Vol. 189, Feb. 3, 1937, p. 50.

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American Miller, 7:323 (1879). On first flour shipment from Minneapolis mills.

———. 8:384 (1880).

Carver, Jonathan. *Travels through the Interior Parts of North-America . . .* 1778. (Opposite p. 70, Falls of St. Anthony, source of chapter head oval of Chapter XIV.)

Clark, V. S. *Op. cit.* (Vol. 2, p. 185, source of the description, quoted by Clark, of St. Anthony Falls as "the most profitable manufacturing locality in the world.")

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———. Vol. 30, Holiday Number, 1890. (P. 5, Minneapolis passes Budapest.)

———. 41:409, 416 (1896).

———. Vol. 208, Nov. 12, 1941, p. 32. On early mislabeling.

Purifier (Sequence Roughly Chronological)

Rollet, Augustin. *Op. cit.*, p. 217. Pinet's machine.

Northwestern Miller, Vol. 199, Production Number, Sept. 13, 1939, p. 2a. Paur.

Kick, Friedrich. *Op. cit.*, p. 212. Paur's machine used on hard Banat wheat.

American Miller, 11:585 (1883). Paur's machine used in France.

Kozmin, P. A. *Op. cit.*, p. 398. (Our Figure 86.)

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Northwestern Miller, 13:174, 250 (1882). Other early Hungarian machines.

———. 48:994 (1899). Barter.

———. 27:530 (1889). "Haxall Process." See also *American Miller,* 39:810 (1911).

———. 5:197 (1877). Cabanes. Translation of article in *Le Génie industriel,* 11:265 (1856). (Source of our Figure 88.)

Benoît, P. M. N. *Guide du meunier* . . . 1863 ed. Par. 278, p. 835. Perrigault.

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———. 11:370 (1883). Start of full-scale manufacture by Smith in 1876.

———. 13:225 (1885); 15:24 (1887); 27:530 (1899). G. T. Smith.

Northwestern Miller, Vol. 16, Holiday Number, 1883. Sales of Smith. On sales, see also *American Miller,* 20:157 (1892).

———. 39:851 (1895). G. T. Smith.

American Miller, 5:71, 87, 107 (1877). Christian's account of Smith. Cf. *Northwestern Miller,* 16:137 (1883).

Northwestern Miller, 29:45 (1890). The traveling brush (claims it for Nicholas La Croix).

———. 9:115 (1880). History of purifier war.

———. 29:29 (1890). Editorial on purifier war.

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Northwestern Miller, 24:32 (1887). Suction vs. blast in purifiers.

American Miller, 8:123 (1880). Electric purifier. See also *Proc. Intern. Conf. on Flour and Bread Manuf.,* 1927, p. 109.

———. 12:462 (1884). Light-beam purifier.

Northwestern Miller, Vol. 210, April 8, 1942, p. 19a. Puro-grader: Hart-Carter catalogues.

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American Miller, 4:43, 121 (1876–1877). American systems.

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Plaisted, H. M. "Milling and Its Machinery," *American Miller,* 11:429, 487, 550 (1883). Surveys all phases of milling.

Proc. Inst. Civil Eng., Vol. 70 (1881–1882). Carr's disintegrator. (Source of our Figure 92.)

NEW-PROCESS MILLING

American Miller, 5:57, 77 (stone dress), 95 (number of purifier patents), 115 (1877).

———. 6:2, 26, 50, 75, 98, 123, 158, 182, 206, 234, 262, 288 (1878). Includes use of rollers.

———. 9:419 (1881). Stages.

———. 10:557 (1882).

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Briggs, Charles H. "The Message of a Ghost That Exploded," *Northwestern Miller,* Vol. 191, Sept. 22, 1937, p. 22. (Source of figures in the text on the explosive force of flour.)

American Miller, 6:49 (1878). On the Tradeston Mills, Glasgow, as planned by Oexle, 1874.

———. 6:49 (1878). On the Washburn A mill before the 1878 explosion.

———. 6:124 (1878). On the great Minneapolis explosion.

———. 9:413 (1881). On dust collectors.

Gray, W. D. *Op. cit.* Very full treatment of dust collectors. (Source of our Figure 95.)

Northwestern Miller, 7:319 (1880). On millstone exhaust.

U.S. Patent 213,151, of March 11, 1879. (Source of specifications for our Figure 96.)

Wheat Cleaning

American Miller, 8:205 (preference of Americans for gentle scouring), 237, 329, 417 (1880).

———. 9:9, 50, 92, 139, 183 (1881).

Nolan, J. D. "Crease Dirt: Its Influence on Flour and the Necessity for Its Removal," *American Miller,* 13:188 (1885). On "Crease-Dirt" theory see also *American Miller,* 19:600 (1891); 31:649 (1903).

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———. 5:94 (1877). Comparisons between millstone and modern flours. See also *Jour. Soc. Arts,* 55:111 (1906–1907).

———. 6:209, 237, 289 (1878). Bolting methods in 1878. *See also* next item.

———. 7:2, 41, 66 (1879). The last article marks the earliest acceptance, in this magazine, of rollers in an American mill, though only for crushing the grain.

———.12:466 (1884). Many grades of chop in Hungarian mills.

Espenschied, Charles. "The Gardner Mill at Hastings, Minn.," *Northwestern Miller,* 23:477 (1887). On the magnetic separator. See also *American Miller,* 30:755 (1902).

Evans, Oliver. *The Young Mill-wright* . . . More middlings, p. 278. On more middlings, see also *Northwestern Miller,* 16:176 (1883).

Kuhlmann, C. B. *Op. cit.,* p. 119. Early purifier profits.

Northwestern Miller, Vol. 21, May 21, 1886, Suppl., p. xii. On action of hexagonal reel.

CHAPTER XV. ROLLERS AND GRADUAL REDUCTION ADVANCE THE MILLING REVOLUTION

General

American Miller, 7:347, 385 (1879).

———. 8:3, 39, 77, 120, 155, 194, 239 (1880).

———. 11:372, 488 (1883).

———. 13:333 (1885). "Diameter and Speed of Rolls, as Affecting Quality and Quantity of Work," by H. B. Shears.

Engineer, 46:105, 255, 347, 403, 434 (1878). Milling machinery at the Paris Exhibition, 1878.

Jenkins, Rhys. *Links in the History of Engineering and Technology.* 1936. Essay 23 deals mainly with early roller mills, through Wegmann. For essentially the same material, see *American Miller,* 15:536 (1887).

Northwestern Miller, 9:344 (1880).

———. 49:950–952 (1900); 50:614 (1900). Controversy between W. D. Gray and the Ganz works on priority.

Reed, J. H. "The First Roller Mill," *American Miller,* 48:968 (1920). Important article on various early American roller mills.

Sulzberger

American Miller, 11:372, 488 (1883); 17:832 (1889).

Gray, W. D. In *Northwestern Miller,* 49:1198 (1899). Stock from the Sulzberger rolls.

Kozmin, P. A. *Op. cit.,* p. 37. Difficulties of the Sulzberger system.

Northwestern Miller, 15:621 (1883).

———. 25:332 (1888). (Source of chapter head oval of our Chapter XV.)

———. 50:614 (1900).

WEGMANN

American Miller, 8:374 (1880).

———. 11:593 (1883).

Northwestern Miller, 23:212 (1887).

GANZ

American Miller, 15:612 (1887).

Northwestern Miller, 69:776 (1907). Ganz corrugation cut, not cast, in.

OEXLE

American Miller, 4:7, 23, 49, 61, 84, 116 (1876–1877).

———. 5:110, 141, 154, 174, 194 (1877).

———. 15:242 (1887).

Northwestern Miller, 10:292 (1880).

———. 11:270 (1881).

Early Roller Milling in Hungary

American Miller, 3:30, 62 (1875–1876).

———. 4:81, 101, 124, 143 (1876–1877).

———. 5:72 (1877).

———. 6:193 (1878).

———. 7:6 (1879).

———. 9:449 (1881).

———. 11:124 (1883).

———. 13:554, 622, 630 (1885).

Kick, Friedrich. In *American Miller*, 3:160 (1875–1876); 6:208, 234, 260, 286 (1878); 7:8 (1879).

Meckel, G. In *American Miller*, 6:27, 52, 74 (1878).

Northwestern Miller, 132:623, 639 (1922). Carries story through World War I.

STATISTICS

Industrie des moulins des pays de la Sainte Couronne Hongroise en 1906. Publ. Statis. Hongroises, New Series 26. 1909.

Northwestern Miller, 11:113 (1881).

———. 12:261, 278 (1881).

Shaw, Albert. "Budapest, the Minneapolis of Europe," *Northwestern Miller*, Holiday Number, 1890, p. 5.

Early American Roller Milling

American Miller, 3:34 (1875–1876); 7:24 (1879). For early American uses of rollers.

———. 11:431 (1883). Extract from catalogue of Edw. P. Allis & Co. An important article. Cf. *ibid.*, 28:454 (1900), which mentions a March 1876 advertisement of rollers.

———. 13:191 (1885).

———. 27:629 (1899).

Engineer, 62:367 (1886).

Northwestern Miller, 11:68 (1881).

———. 23:178 (1887).

Early English Roller Milling

American Miller, 15:387 (1887).

———. 30:397 (1902). On Francis Stallmaier.

Encyclopaedia Britannica, 9th ed., article "Flour, Manufacture of." Excellent description of modern milling processes as of 1879.

Engineer, 63:317 (1887).

Northwestern Miller, 23:142 (1887).

———. Vol. 214, May 9, 1943, p. 12a. About J. A. A. Buchholz; the claim that he made the first flow sheet is unfounded.

———. Vol. 218, May 31, 1944, p. 22. Mainly about G. A. Buchholz.

Millstones vs. Rollers

American Miller, 4:84 (1876). (Source of our Hungarian comparisons.)

———. 8:374 (1880).

———. 10:514 (1882). By Bryan Corcoran, an English defender of the millstone.

———. 10:564 (1882). "A Baker's Opinion of Rolls and Stones," by W. A. Thomas.

———. 11:175 (1883). An article by Henry Simon advocating rolls.

———. 11:423 (1883). "A British View of the Millstone Question."

———. 12:300 (1884). "The Profits of the Two Systems."

Northwestern Miller, 16:278 (1883).

———. 19:448 (1885). Symposium of opinions of Minneapolis millers. Cf. *ibid.*, 30:255 (1891).

———. 20:574 (1885).

COMPARISON OF EXTRACTIONS

American Miller, 11:536 (1883).

———. 13:630 (1885). Extractions for 1873–1874.

———. 16:318 (1888).

Miscellaneous

Abernathey, R. J. In *American Miller*, 9:364 (1881). Quoted in text.

American Miller, 3:34 (1876). R. L. Downton and germ problem. On germ problem see also *ibid.*, 15:662 (1887) (article by Gilbert Little on Thomas Muir), and on the present English treatment, J. F. Lockwood, *op. cit.*, p. 364.

———. 9:3 (1881). Early roller corrugations. See also *ibid.*, 25:23 (1897).

———. 9:470 (1881). Roller extractions in 1881.

———. 15:461 (1887). Source of the quotation in our text, p. 230, on the "iron mine and lumber yard" in German machines.

———. 15:817 (1887). Source of the quotation in our text, p. 234, on the flimsiness of the frame in Hungarian machinery.

Bakers Weekly, Vol. 45, March 7, 1925, p. 76. Minneapolis 1873 committee to investigate European milling.

Chisholm, S. S. "Development of Gradual Reduction," *American Miller*, 10:463 (1882). Quoted in text.

Gray, W. D. In *Northwestern Miller*, 48:721, 1092 (1899). Quoted in motto of Chapter XV and in text.

Lawson, P. V. "The Invention of the Roller Flour Mill," *Proc. State Hist. Soc. Wisconsin*, 1907, p. 244. Makes broad claims in behalf of John Stevens. Cf. *American Miller*, 48:968 (1920); *Northwestern Miller*, 11:3 (1881).

Northwestern Miller, Vol. 234, June 1, 1948, p. 8. Rope and belt drives.

CHAPTER XVI. THE AUTOMATIC ALL-ROLLER GRADUAL-REDUCTION MILL COMPLETES THE REVOLUTION

Clark, M. W. "American Roller Milling," *American Miller*, 13:404 (1885). Excellent survey for an English audience.

de la Barre, William. "Recollections of a Milling Engineer," *Northwestern Miller*, 186:202, 779 (1936). (The latter for statement that the first use of chilled-iron, corrugated rolls for break in the United States was in the experimental mill.) *Ibid.*, 187:196 (1936) (conversation with Pillsburys). Cf. *ibid.*, 185:814 (1936). Important articles, especially for Washburn experimental mill.

Gibson, L. H. *Gradual Reduction Milling*. 1885. This book is summarized and extensively quoted in Pamphlet 2, *Technical Education Series*, of the English National Joint Industrial Council for the Flour-Milling Industry. Its substance appeared in the *Northwestern Miller*, beginning with Vol. 11 (1881), in articles entitled "Some Hints on Gradual Reduction." From Vol. 14 (1882), the articles were called "Rough Notes."

Gray, W. D. *Op. cit.* For Washburn experimental mill.

Neftel, Knight. *Report of Flour-Milling Processes*. Tenth Census of the United States, Agriculture, Vol. 3. 1883. This report, prepared in 1880 and 1881, gives a clear picture of the best American milling practice of the time. There are full descriptions, with large drawings, of the Washburn and Pillsbury A mills.

Shears, H. B. "What System Shall I Adopt?" *American Miller*, 11:485 (1883). Important article; declares for chilled-iron rollers.

American Gradual Reduction

American Miller, 8:40, 76, 119, 156, 198, 236, 330, 370, 417 (1880); 9:10, 52, 95, 139 (1881). An early American attempt to cover the entire subject, including various systems.

———. 8:309 (1880). "Have We a System of Milling?" Cf. *ibid.*, 9:114, 419 (1881).

———. 10:104, 149, 194, 244, 299, 346, 399, 448, 500, 549 (1882). Another series.

———. 10:463 (1882).

———. 11:21, 480 (1883).

English Gradual Reduction

Carter, J. H. In *American Miller*, 8:55 (1880); 10:401 (1882).

Engineer, 62:479 (1886).

Northwestern Miller, 12:365 (1881).

Simon, Henry. In *American Miller*, 8:385 (1880).

———. "Different Systems of Grinding," *ibid.*, 10:552 (1882).

———. "Evolution of the Roller Mill," *ibid.*, 11:8, 58, 108 (1883). A series.

———. "Advantages of Rolls Compared with Stones," *ibid.*, 11:175 (1883).

———. "Quantity and Quality of Roller Flour," *ibid.*, 11:331 (1883).

———. "Record of Tests as to the Power Consumed by Various Machines Used in Roller Mills," *ibid.*, 15:479 (1887).

———. In *Northwestern Miller*, 13:72 (1882).

———. *Ibid.*, 22:465 (1886).

Early Minneapolis Roller Mills

Northwestern Miller, Vol. 14, Export Edition, Oct. 15, 1882, p. 7. For a description of all Minneapolis mills as of 1882.

———. Vol. 15, Supplement, June 1, 1883. Under "Trade Talk." Additional material on Minneapolis mills.

———. Vol. 24, Holiday Number, 1887, p. 2. Slightly later description than in articles above. Cf. *American Miller*, 24:23 (1896).

WASHBURN EXPERIMENTAL MILL

American Miller, 7:12, 206 (1879).
———. 30:830 (1902).
Northwestern Miller, 16:584 (1883).
———. 25:156 (1888).
———. 47:1181 (1899).
———. 48:1145, 1198, 1215, 1243 (1899). Articles by W. D. Gray.
———. 49:950 (1900).
———. 185:814 (1936).

WASHBURN A MILL OF 1880

American Miller, 7:405 (1879).
———. 8:283 (1880).
Northwestern Miller, 9:198 (1880).
———. 10:4 (1880).
———. 31:124, 125 (1891). On the 1891 reconstruction of this mill.

WASHBURN C MILL

American Miller, 7:205 (1879).

PILLSBURY EXCELSIOR MILL OF 1881

Northwestern Miller, Vol. 14, Export Edition, Oct. 15, 1882, p. 17.

PILLSBURY A MILL OF 1881

American Miller, 9:403 (1881).
Northwestern Miller, 11:217, 220 (1881).
———. 28:547 (1889). Describes east side (1881), west side (1882), introduction of steam power (1884), and later developments.

PILLSBURY B MILL OF 1881

Northwestern Miller, 12:323 (1881).
———. 28:547 (1889). Describes mill as fitted out in 1885.

ANCHOR MILL OF 1886

Northwestern Miller, 28:549 (1889).

Date of All-Roller Milling at Budapest

American Miller, 17:28 (1889). By W. R. Voller. Cf. the following articles:
———. 3:30 (1875–1876).
———. 4:23 (1876–1877).
Northwestern Miller, 10:292 (1880).
———. 14:92 (1882). From *Die Mühle*.

Special Methods

American Miller, 7:290 (1879). Nagel and Kaemp System. See also *Northwestern Miller*, 13:367 (1882).
———. 9:449 (1881). Early competitors of rollers. See also *ibid.*, 27:59 (1899).
———. 10:398, 513 (1882). Louis Gathmann. See also *ibid.*, 13:296 (1885); 31:649 (1903).
———. 10:402, 449, 501 (1882). Jonathan Mills. See also *ibid.*, 16:260a (1888); 29:531 (1901); *Northwestern Miller*, 18:132 (1884); Vol. 21, May 21, 1886, Supplement, p. viii.
———. 13:296 (1885). Seidl's 1885 mill near Vienna.
———. 14:192 (1886). The flow sheet.
———. 30:397 (1902). Francis Stallmaier. See also *ibid.*, 31:407 (1903).
Engineer, 63:317 (1887). J. A. A. Buchholz.
Northwestern Miller, 12:446 (1881). Seck System.
———. 69:706 (1906). G. A. Buchholz.
———. 185:814 (1936). Sellers Mill.

Milling Exhibitions

Northwestern Miller, 9:376 (1880). On Cincinnati Exhibition of 1880. See also *Engineer,* 50:4 (1880)—English account; numerous names misspelled—and *American Miller,* 27:949 (1899); 30:316 (1902); 33:1005 (1905).

Engineer, 50:52, 90 (1880). On exhibition at Carlisle, England, 1880.

Northwestern Miller, 11:377, 380 (1881). On exhibition at London, 1881.

Miscellaneous

American Miller, 11:19 (1883). Application of rollers to soft winter wheat. See also *ibid.,* 13:199 (1885).

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CHAPTER XVII. THE BUSINESS SIDE OF MILLING GAINS IMPORTANCE

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(Our Figure 112 is derived from data in the *Northwestern Miller Almanacks;* cf. *Wheat Studies,* Vol. 2 (1925–1926), p. 237, for production before 1902.)

CHAPTER XVIII. THE MODERN MILL AND ITS FLOUR

This chapter is based mainly on the Dunwoody Industrial Institute's "Correspondence Course in Practical Milling," 1937–1940, which furnished the data for the 500-barrel mill analyzed and was also the source for our Figures 82, 85, 103, 107, 125, and 126. A mimeographed supplement to this course was prepared by General Mills for its employees; it was the source of Figures 118–120. Among other publications of General Mills that were utilized were *The Flour Business* (1948), prepared for employee study groups; *A Nutrition Guide: The Story of the Cereal Grains* (1944); the Company's *Annual Reports; General Mills Horizons,* a magazine for stockholders; *The Modern Millwheel,* a magazine for employees; *Progress through Research,* a quarterly; the Company's *Functional Manual;* and mimeographed material entitled *The Organization of General Mills* (1947).

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———. Vol. 207, Aug. 20, 1941, p. 28. Distribution of milling costs.

———. Vol. 225, March 12, 1946, p. 3a. High-extraction war bread.

———. Vol. 232, Dec. 9, 1947, p. 24. Self-rising flour.

———. Vol. 232, Dec. 30, 1947, p. 10. Rise of Kansas City.

———. Vol. 233, Feb. 10, 1948, p. 1a. Power requirements of the modern mill. See also *ibid.*, Vol. 234, May 11, 1948, p. 24a; *Electric Jour.*, 30:496 (1933).

U.S. Census of Manufactures. (Source of data for all American mills in our Figure 115. Moody's *Industrials* is the source of the data for General Mills.)

CHAPTER XIX. THE NEW ERA OF ORGANIZATION AND RESEARCH

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CHAPTER XX. LOOKING FORWARD

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